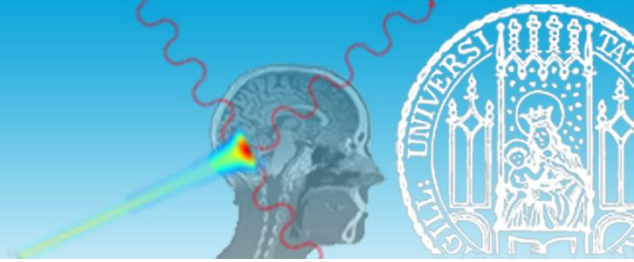

Toward a new Treatment Planning Approach accounting for in-vivo proton range verification

Ludwig-Maximilians-Universität, München
Liheng Tian

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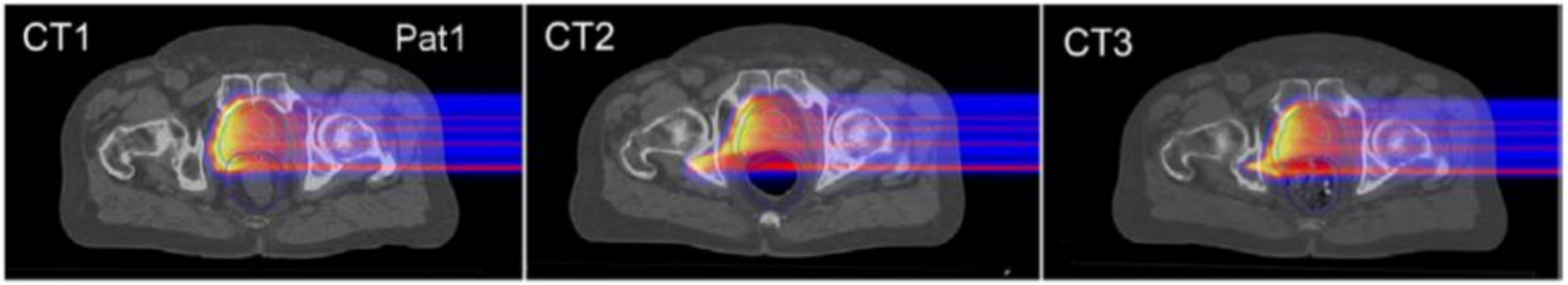
Introduction

- Proton range uncertainties



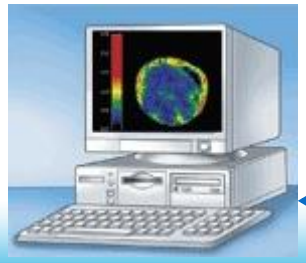
  - CT number conversion
  - Anatomical changes
  - Patient set up
  - …

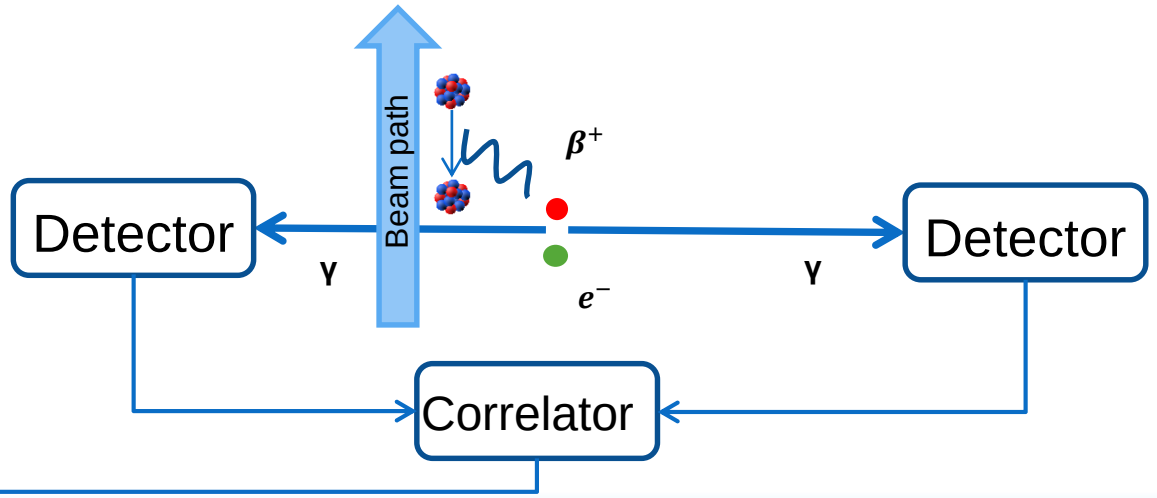
Introduction

- In-vivo proton range verification
  - Positron Emission Tomography (PET)

    Detection of annihilation photons from the decay of β^+-emitters

    1. Takes few tens minutes to use PET scanner
    2. Disturbed by organ motion and washout effect



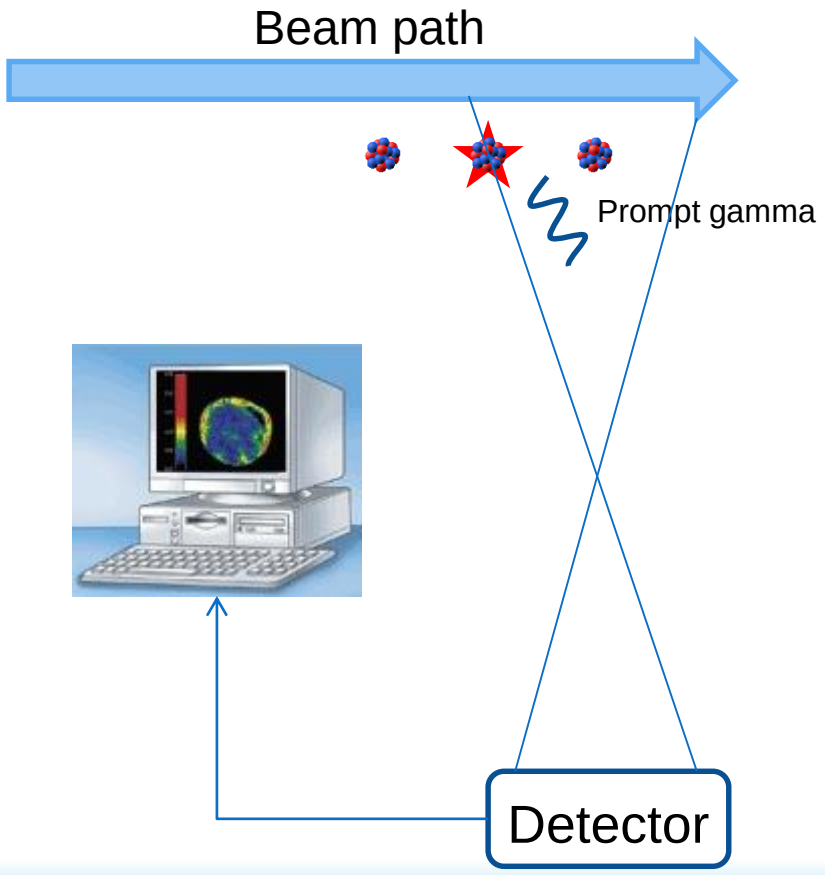


Introduction

- In-vivo proton range verification
  - Prompt Gamma (PG) Imaging

    Monitor the Prompt Gamma emitted by nuclear de-excitation of nuclei in the beam path

    1. Fast (within nanoseconds)
    2. Better PG-dose signal comfirmation
    3. Higher gamma production rates
    4. Clinical experiment shows that the retrieval precision of 2mm can be achieved



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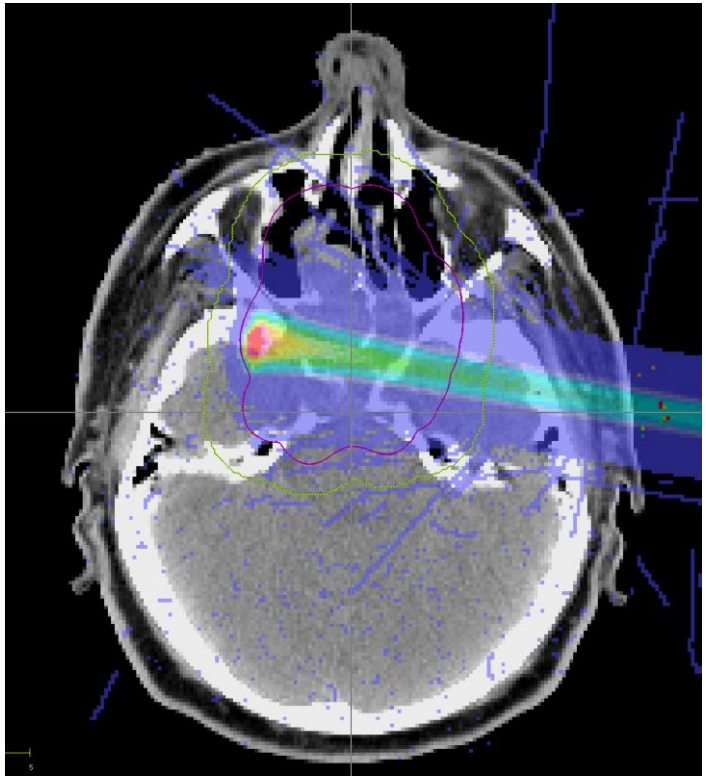
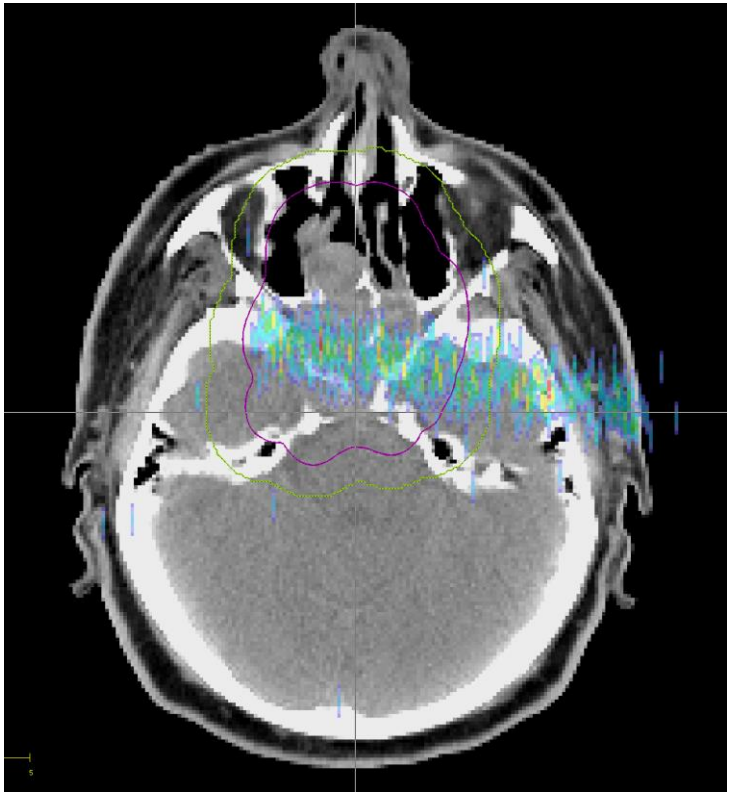
Introduction



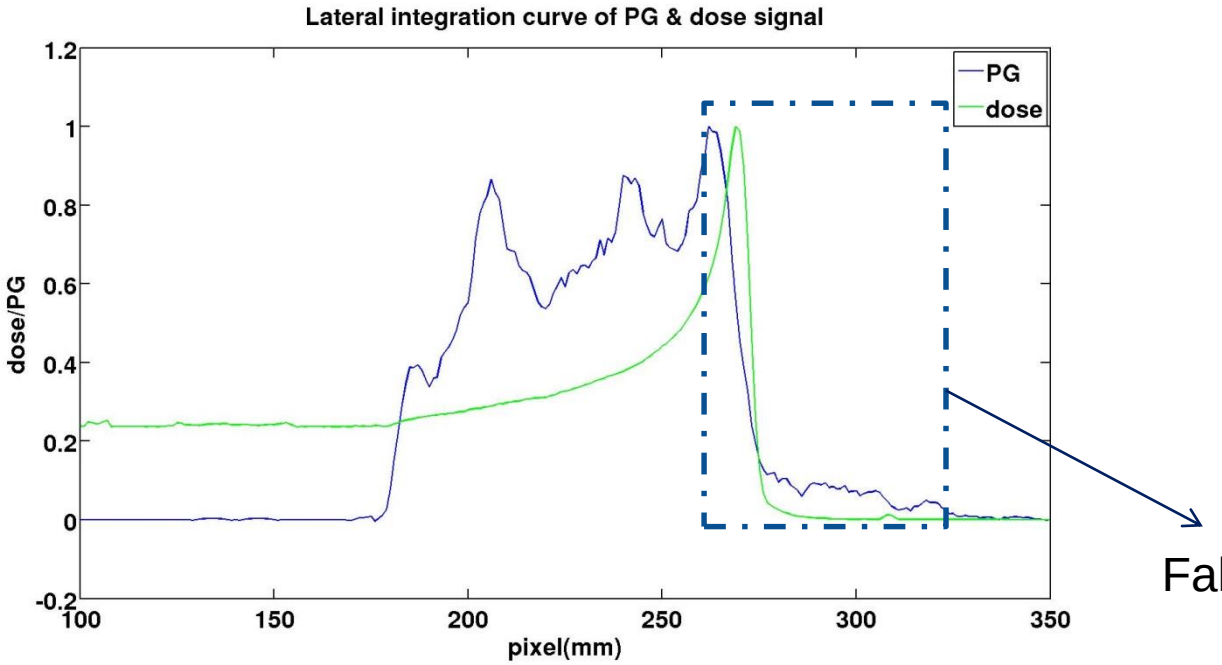
Dose delivery



PG emission

Introduction

- Ideal PG & dose profile



Fall-off region

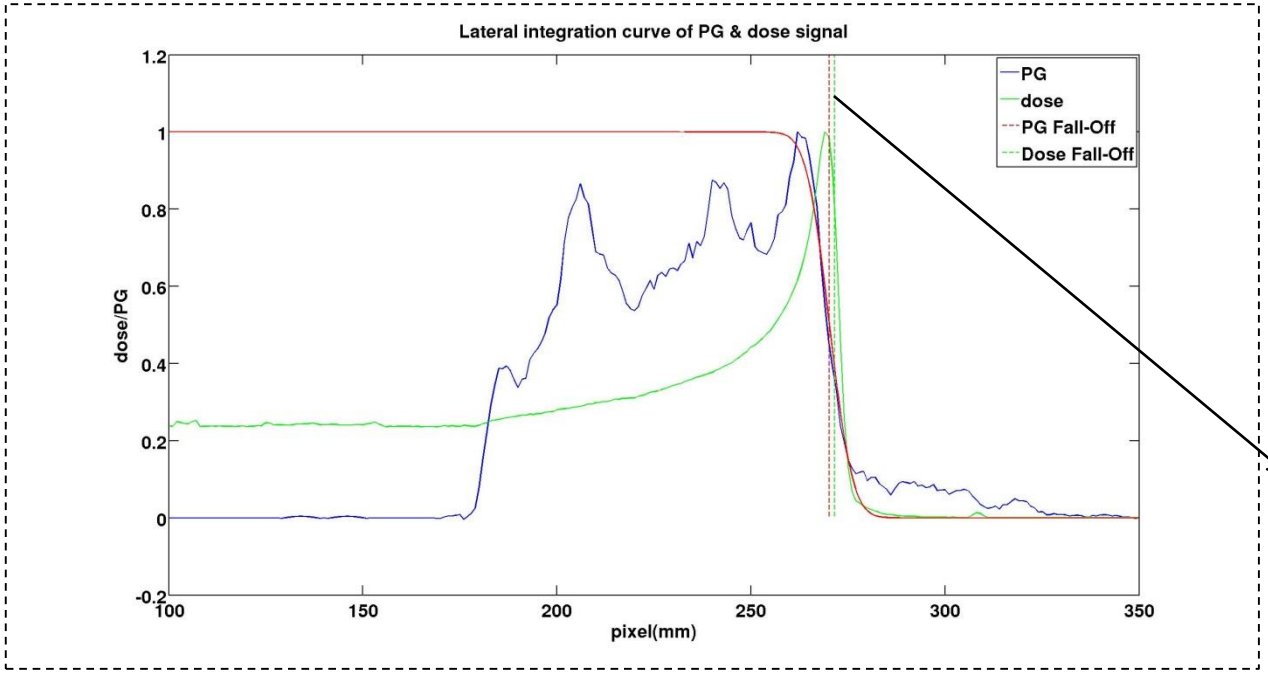
Lateral integration of PG & dose signal

c: Fall-off position
1/b : Fall-off slope

$$F(x) = a + (1 - a)\mathrm{erf}[b(x - c)]$$

Introduction

- Ideal PG & dose profile



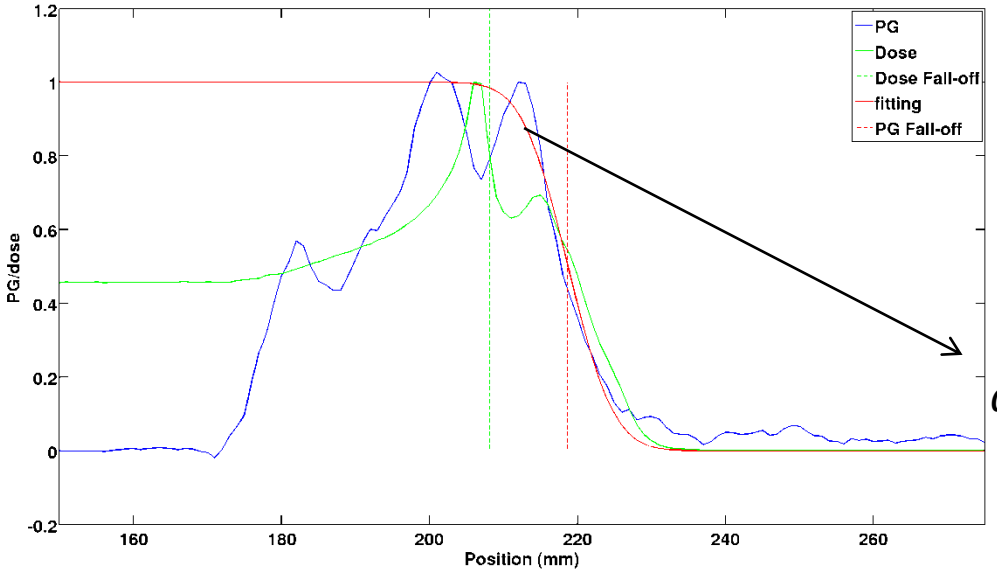
$dR = -1.30\ mm$

Lateral integration of PG & dose signal

Distance between PG and dose fall-off position:
dose: distal 80% dose fall off
PG : fitting function

Introduction

- However, the correlation between PG and dose signal is not always good



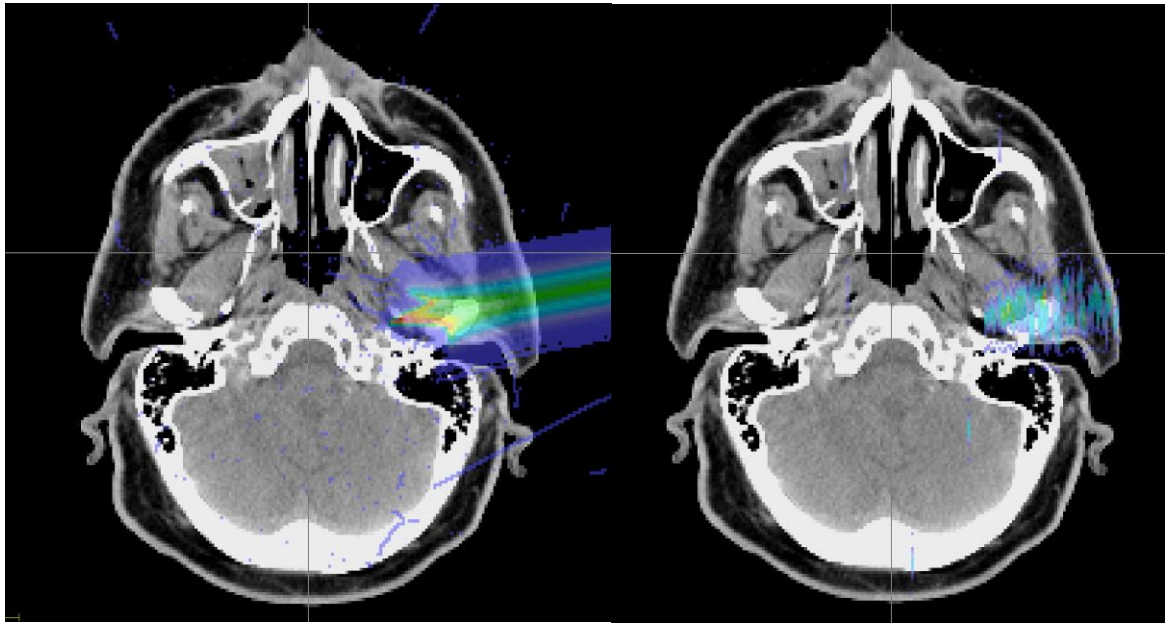
$dR = -8.6\,mm$

Lateral integration of PG & dose signal

Introduction

- Reason

  Tissue inhomogeneity (bone/air in beam path)



Dose delivery PG emission

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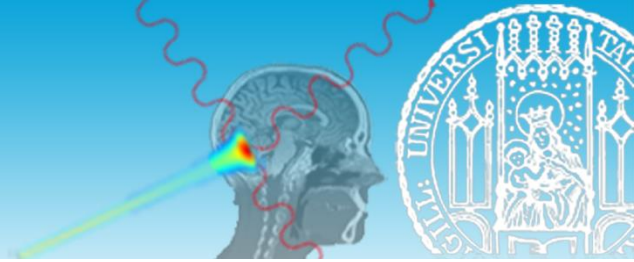
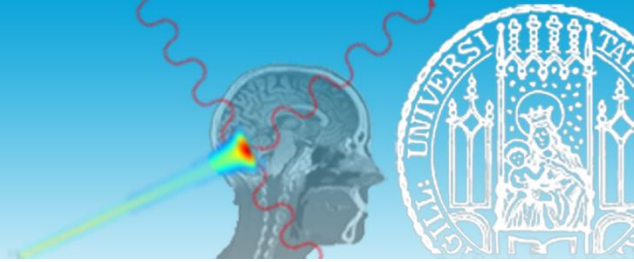
Introduction



- The PG-dose correlation of individual pencil beam is not considered in current treatment planning system (TPS)

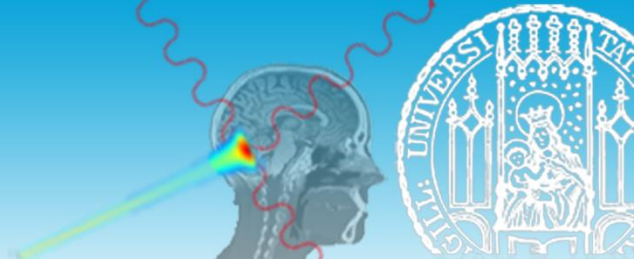
Goal



- Goal of my study:

  Optimize current TPS system, accounting for in-vivo proton range verification to enable a reliable treatment monitoring

Method



1. Quantify and identify the degree of ‘PG-dose correlation’ for each spot

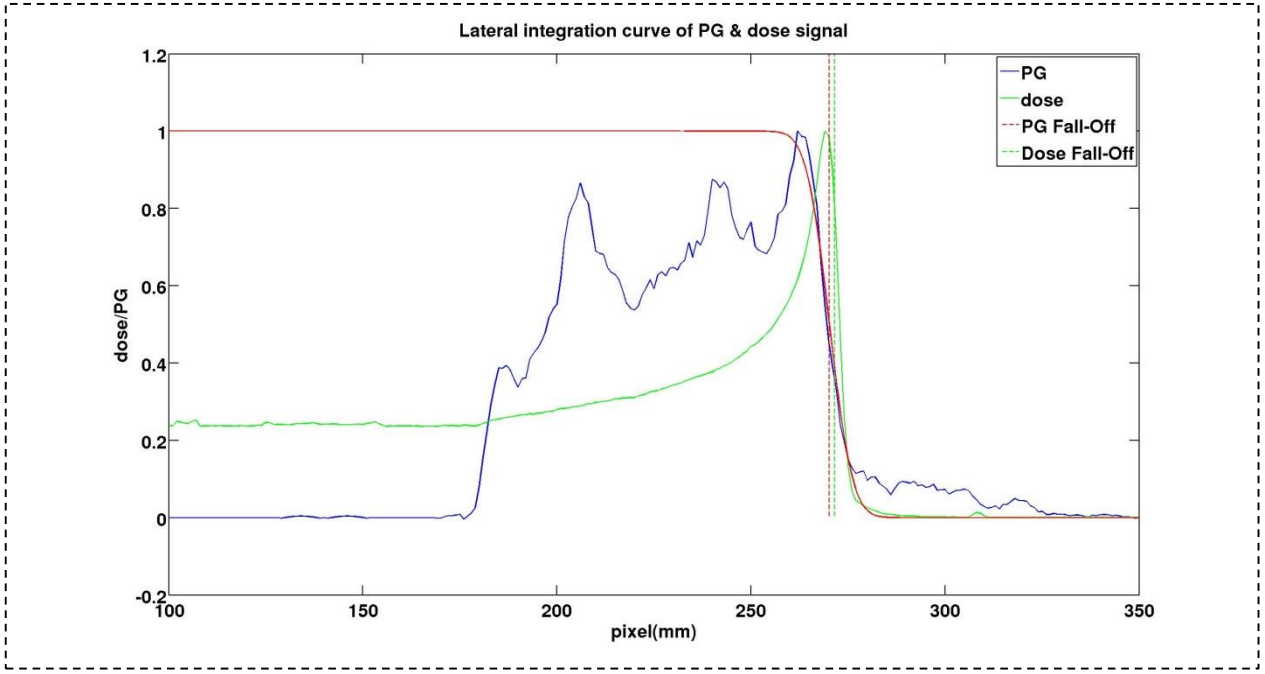
Criteria:

- Distance between the Fall-off positions of PG & dose profile (dR)
- Slope of the PG signal Fall-off region (1/b)
- Fitting quality (Sum of squared errors, SSE)

Method

- Example:

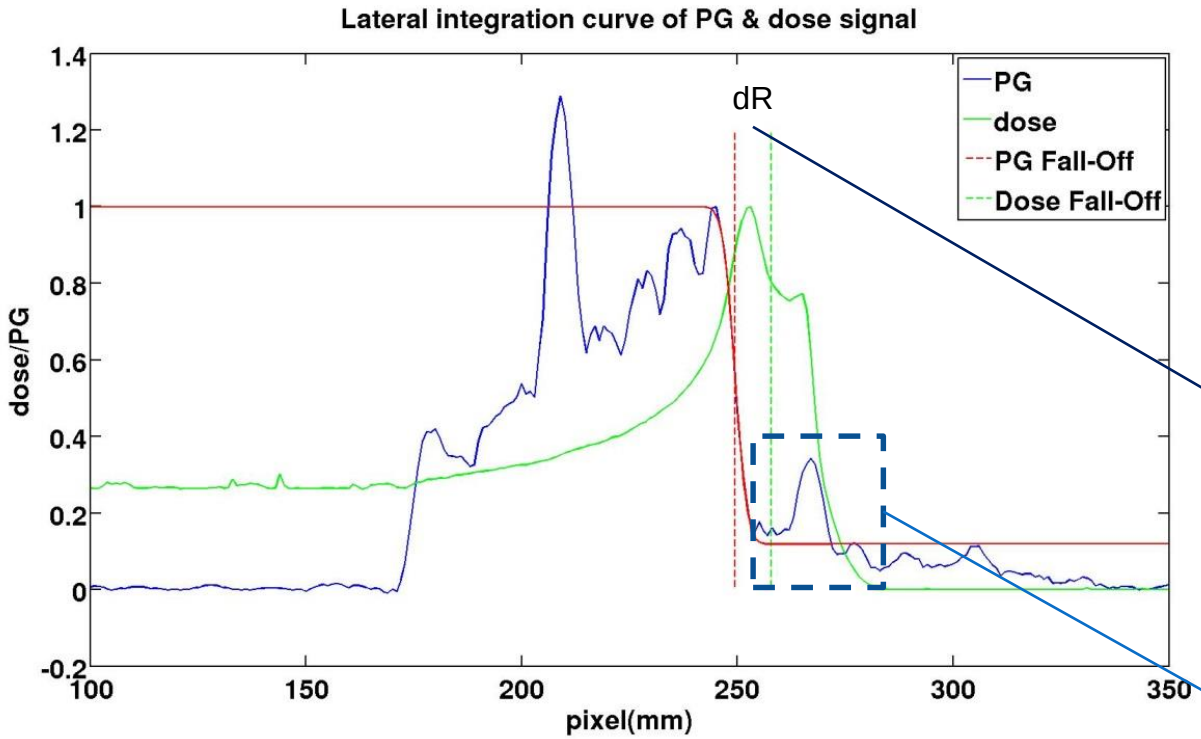
  Ideal case:



Method

- Example:

  Poor correlation case 1:



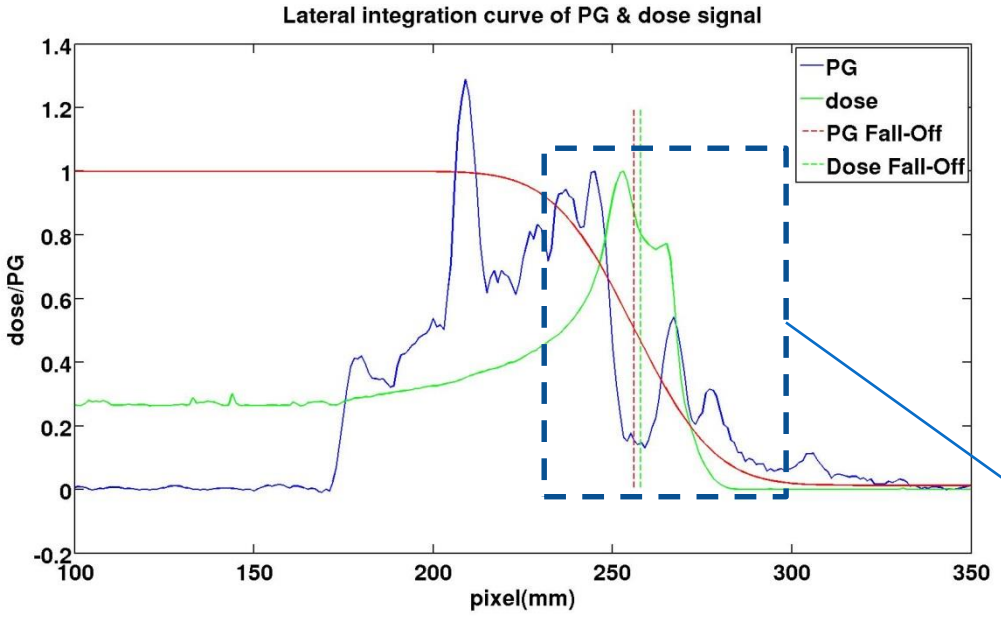
Large dR relates to poor correlation directly

A secondary peak, relating to an air cavity, leads to high SSE value

Method

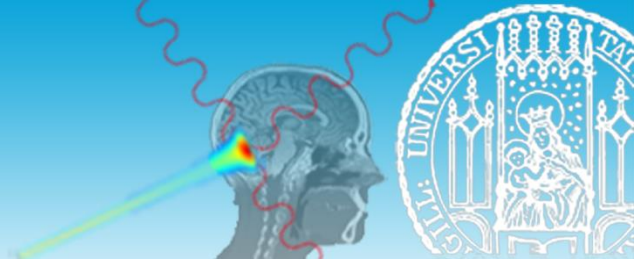
- Example:

  Poor correlation case 2:



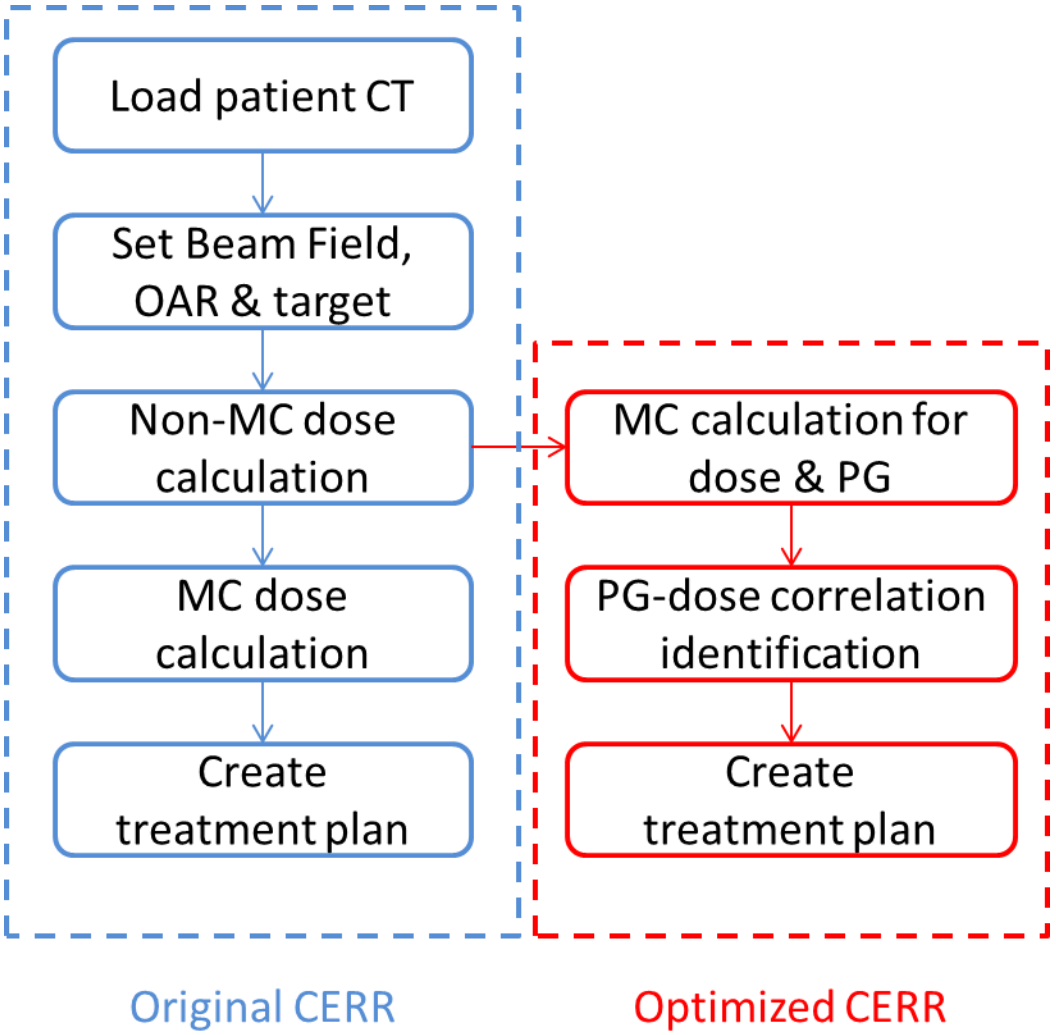
A shallow slope related also to an air cavity, causing the failure of fitting

Method



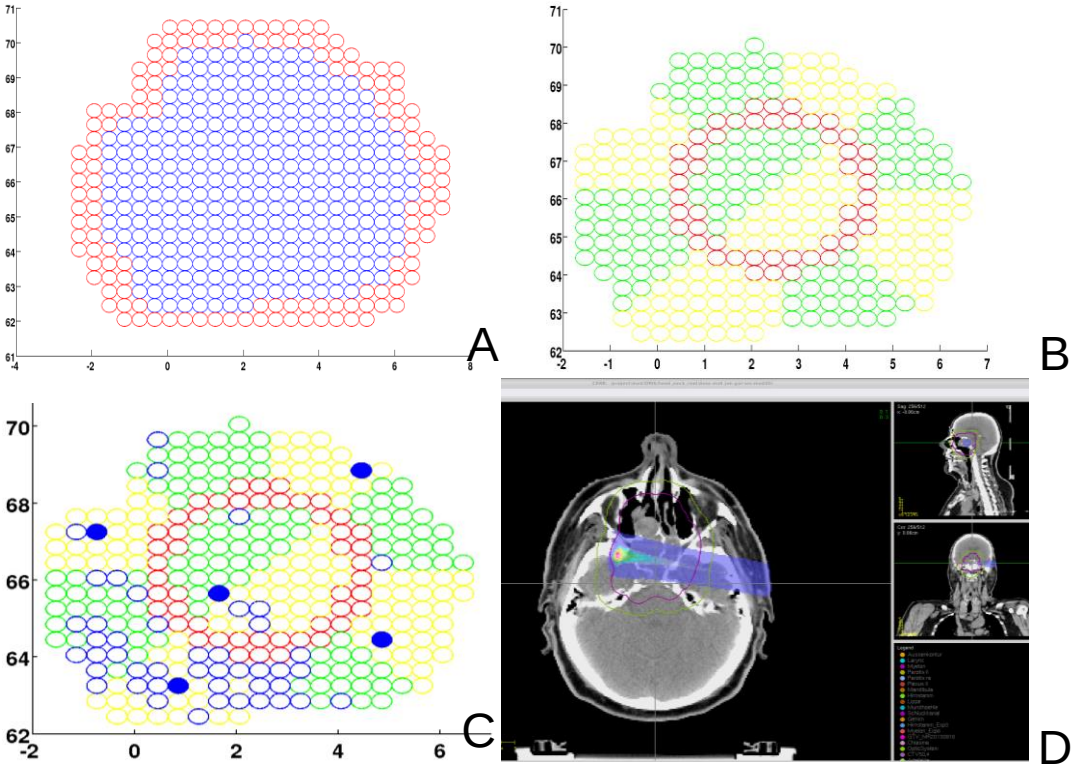
1. Quantify and identify the degree of ‘PG-dose correlation’ for each spot
2. Improve the initial treatment plan while maintaining the quality of plan

General workflow of CERR TPS and our improved TPS:



Method

- Boost few spots which have the best PG-dose correlation



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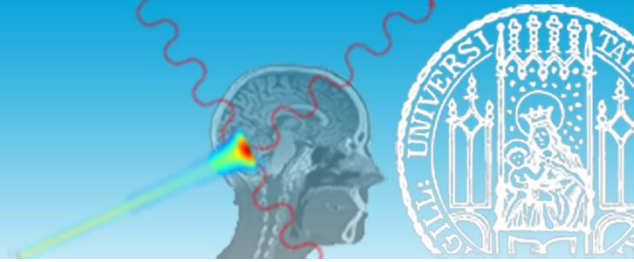
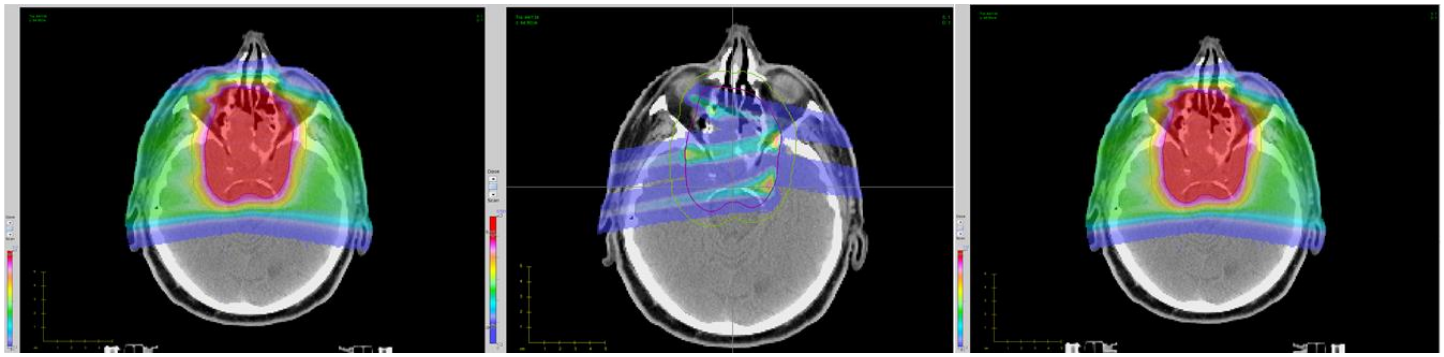
Result

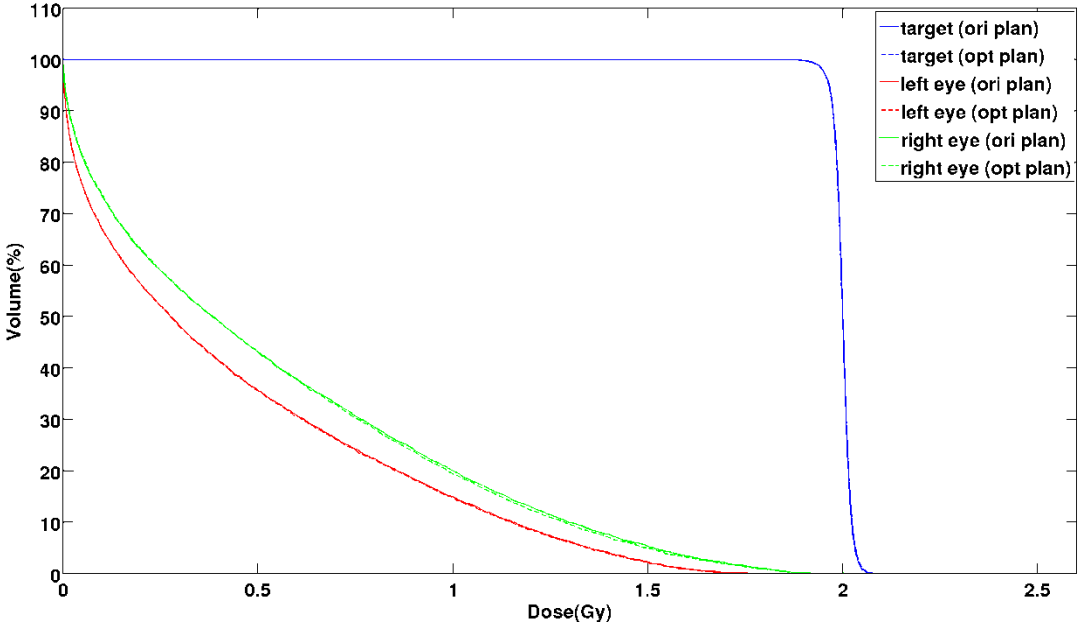


- Dose delivery
- PG-dose correlation

Dose delivery



Patient 1



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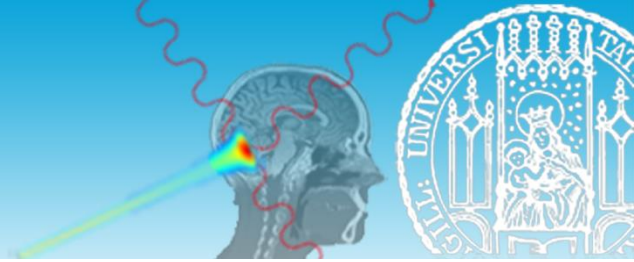
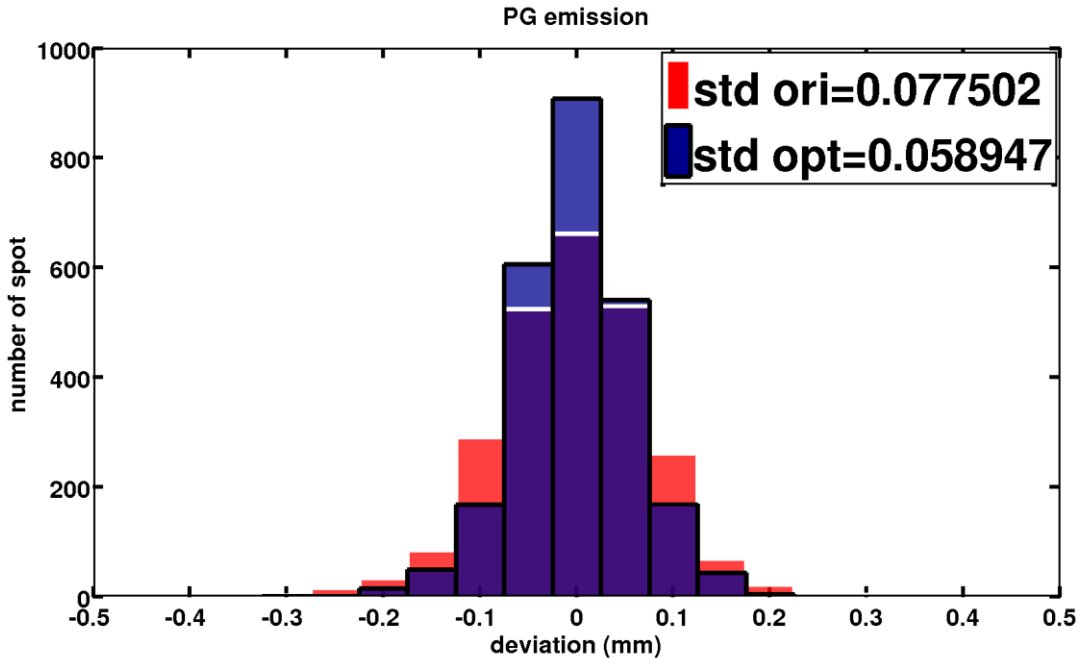
Result



- Dose delivery
- PG-dose correlation

Robustness of fitting:

10 highest-intensity spots in both plans are simulated 25 times, the number of protons in each individual simulation is 10^7
Fitting for each individual simulation (10^7) is compared to full simulation (10^8) of the same spot to evaluate the robustness of fitting

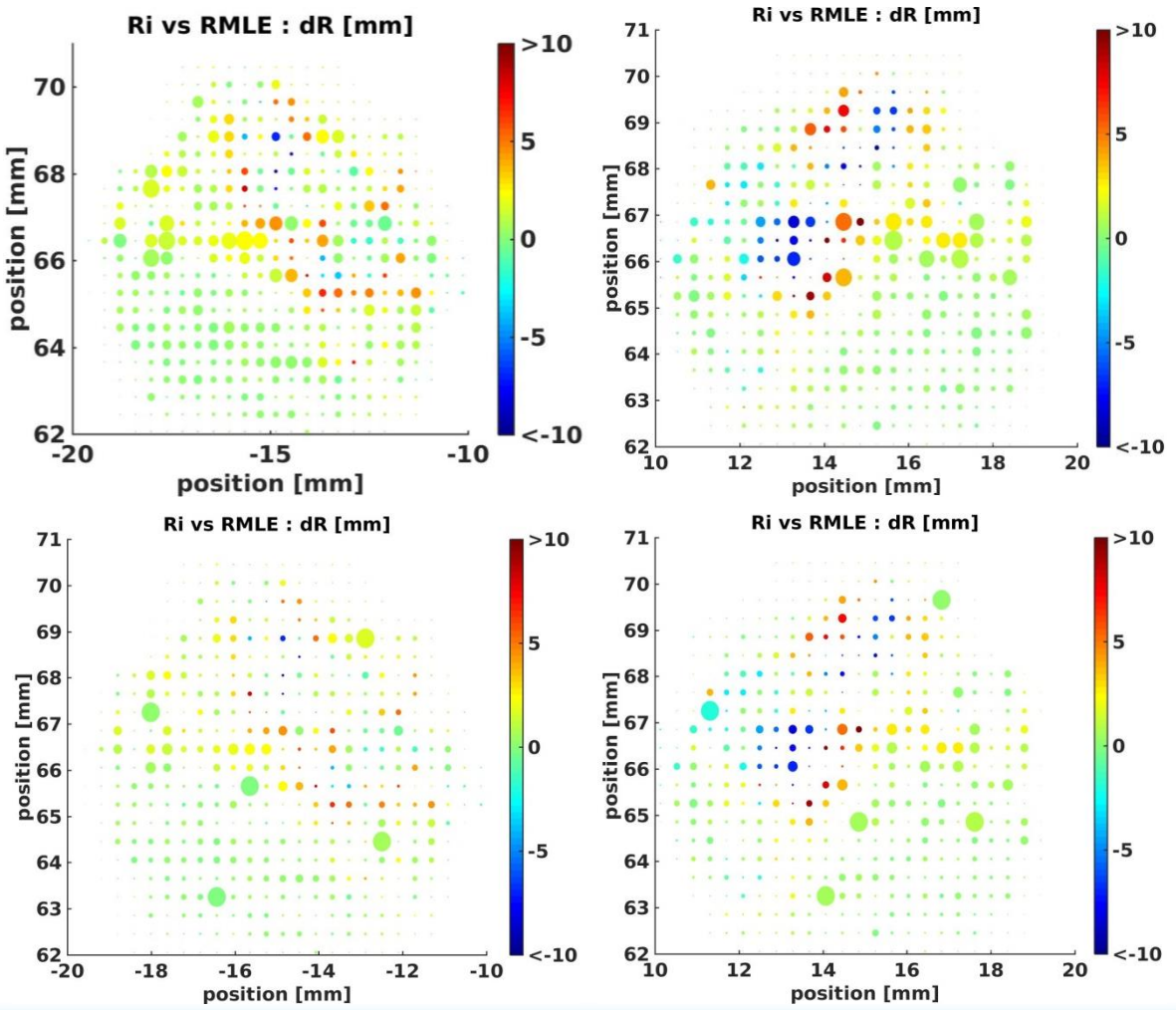


PG-dose correlation

Beam's eye view:

The color shows the PG-dose correlation and

The spot radius is linearly proportional to the proton number



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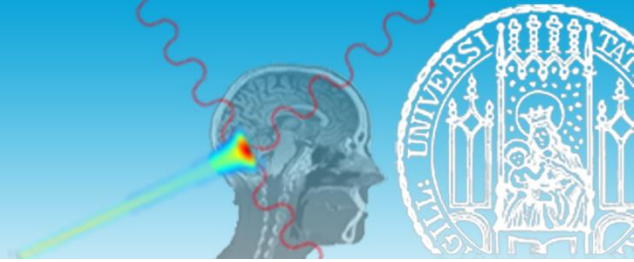
Result



Currently, our new approach is able to:

- Quantify and identify spot-by-spot PG dose correlation automatically in a MC treatment planning process
- Provide the user with candidate spots which have reliable PG-dose correlation
- Optimize a treatment plan which is comparable to the initial treatment plan in terms of dose distribution. Besides, few high-intensity spots in the new plan could provide reliable in-vivo proton range verification

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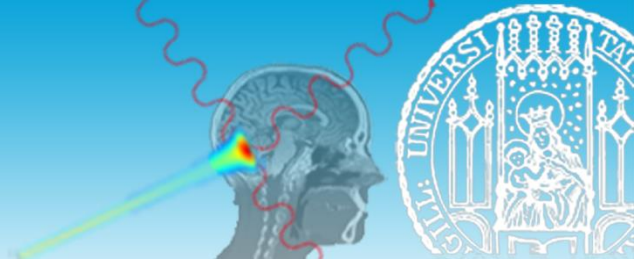
Conclusion



Though different issues are still needed to be addressed, with the results of this project, the treatment planning process in proton therapy could be improved, by integrating the PG-based in-vivo monitoring of the beam range

This novel approach could lead to a safer and more controllable proton treatment in the future

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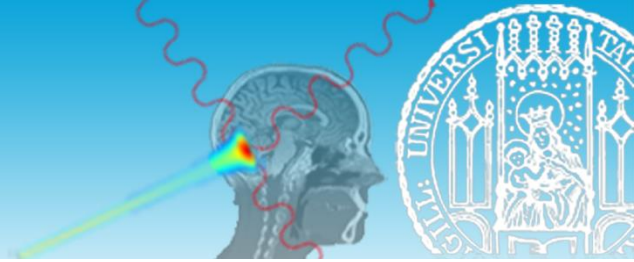
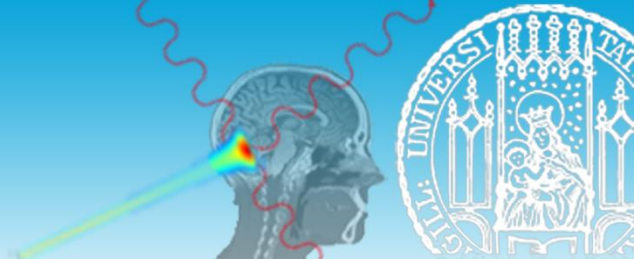
Current work



- Detection devices signal is different from PG emission
- Robustness of PG-dose correlation considering anatomical change and different uncertainties



Thank you!