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

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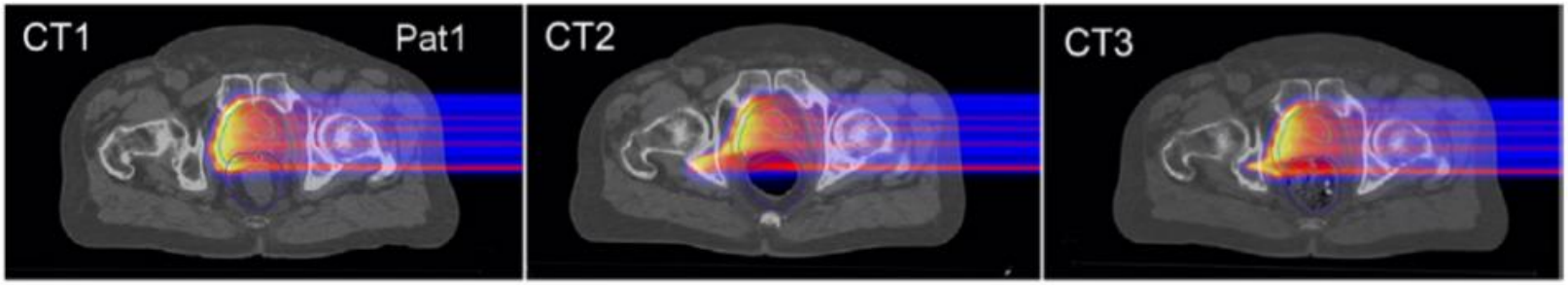
Introduction

- Proton range uncertainties



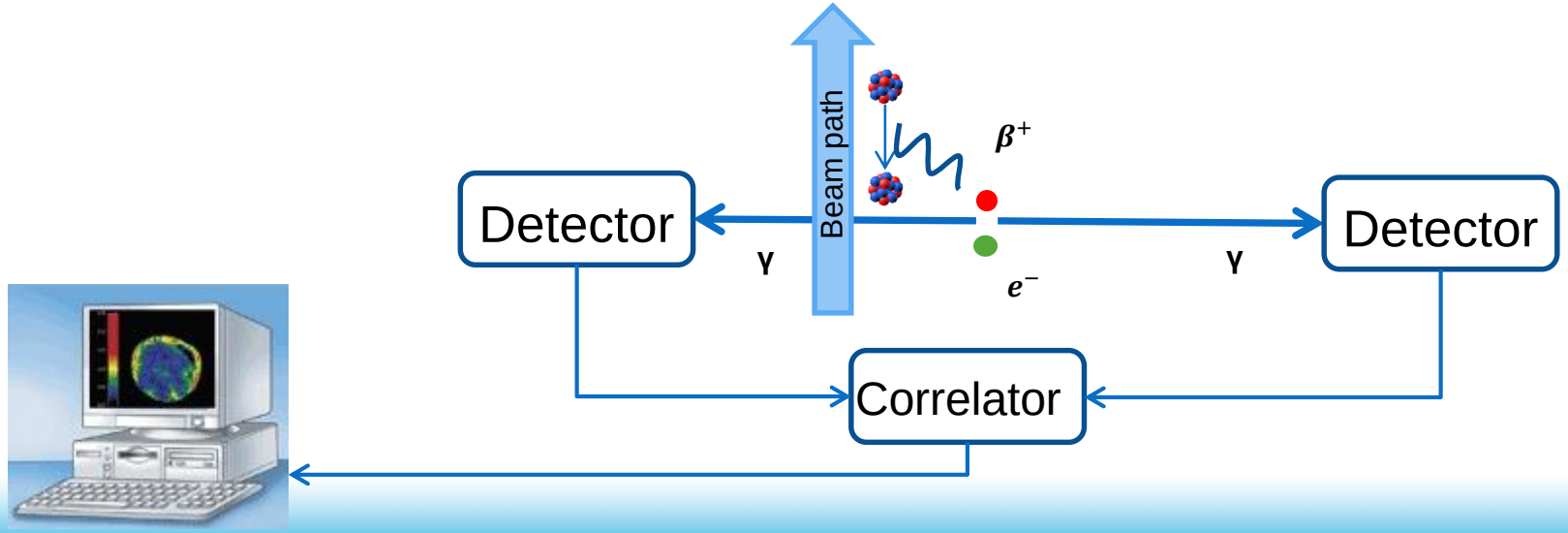
- CT number conversion
- Anatomical changes
- Patient set up
- …

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

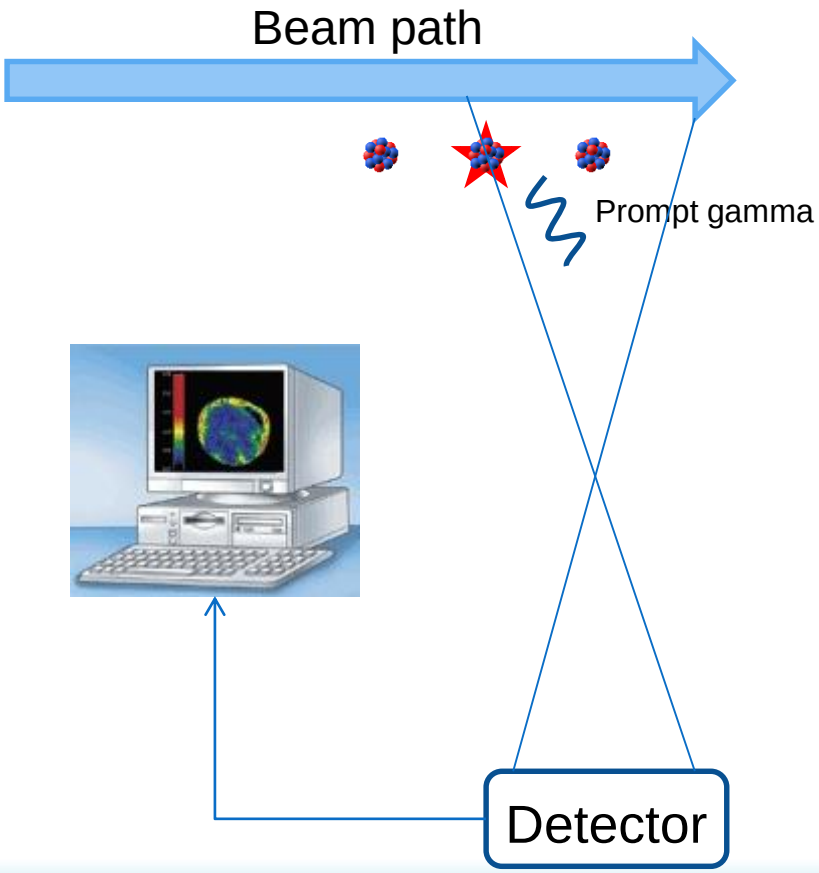


Introduction

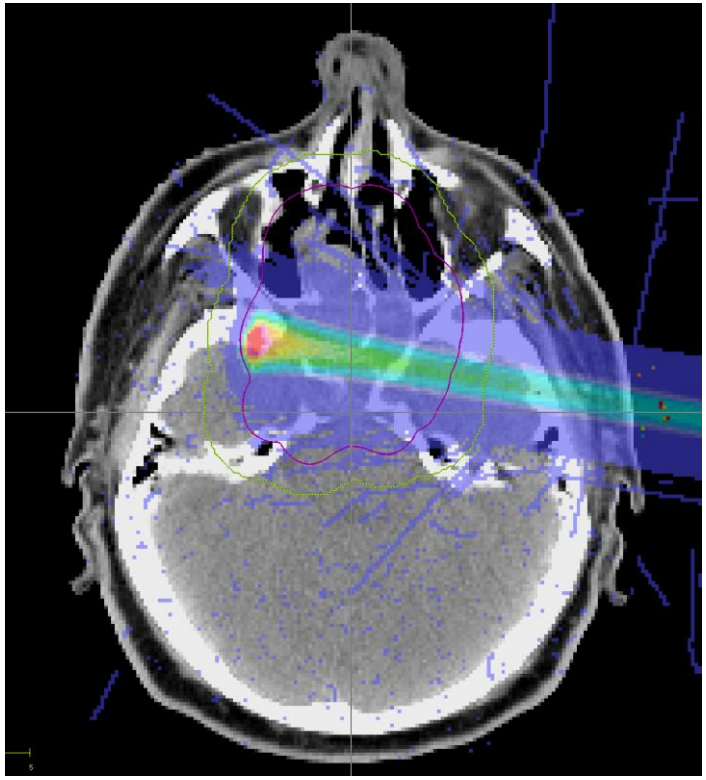
- In-vivo proton range verification
  - Prompt Gamma (PG) Imaging

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

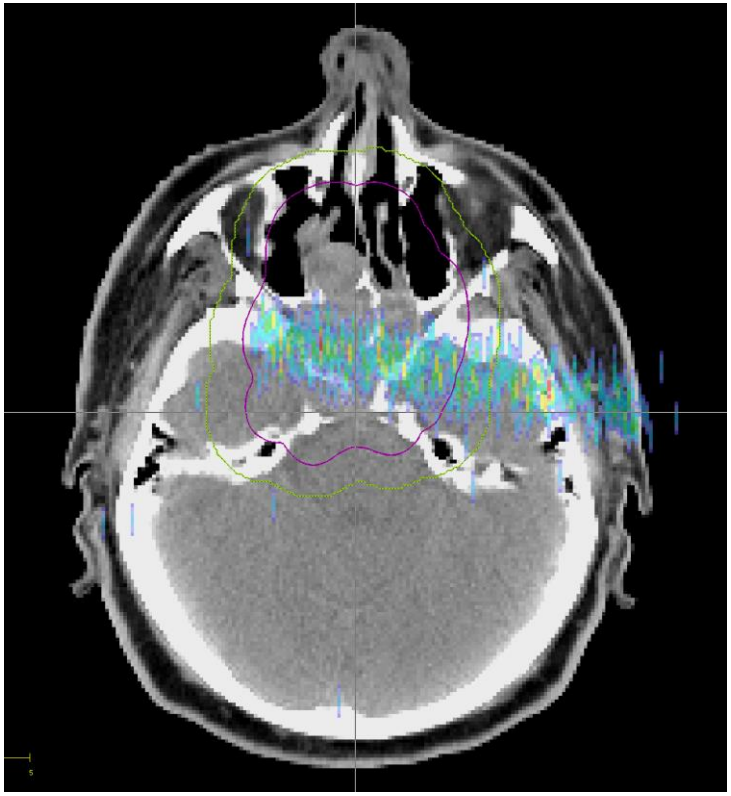
    1. Fast (within nanoseconds)
    2. Better PG-dose signal comfirmation
    3. Higher gamma production rates
    4. Clinical experiment shows that the retrieval precision of 2mm can be achieved



Introduction



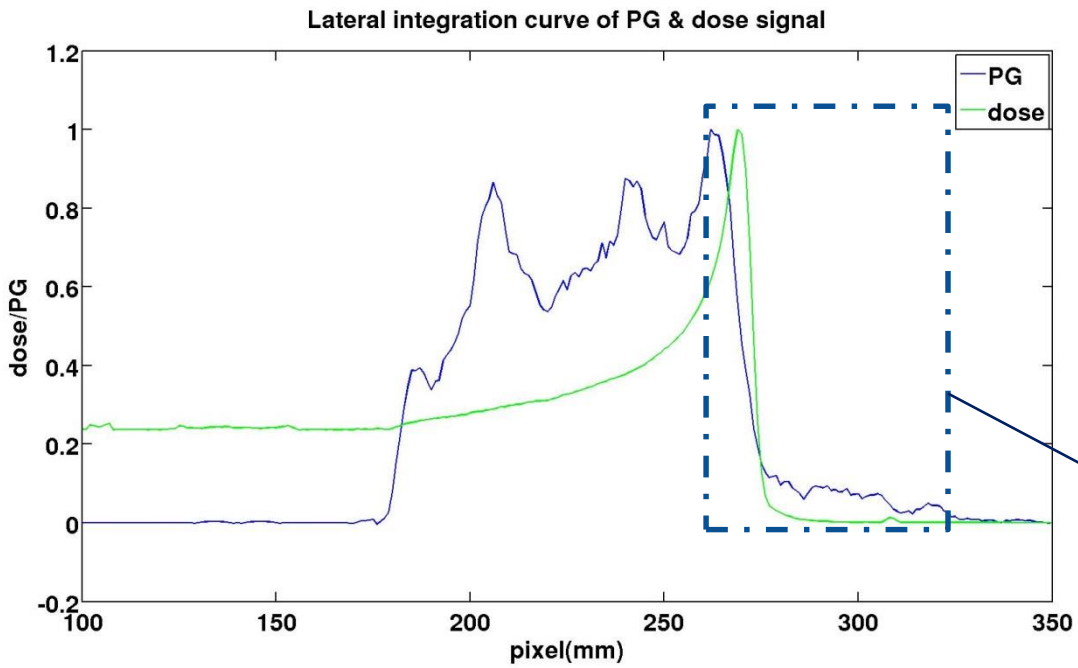
Dose delivery



PG emission

Introduction

- Ideal PG & dose profile



Fall-off region

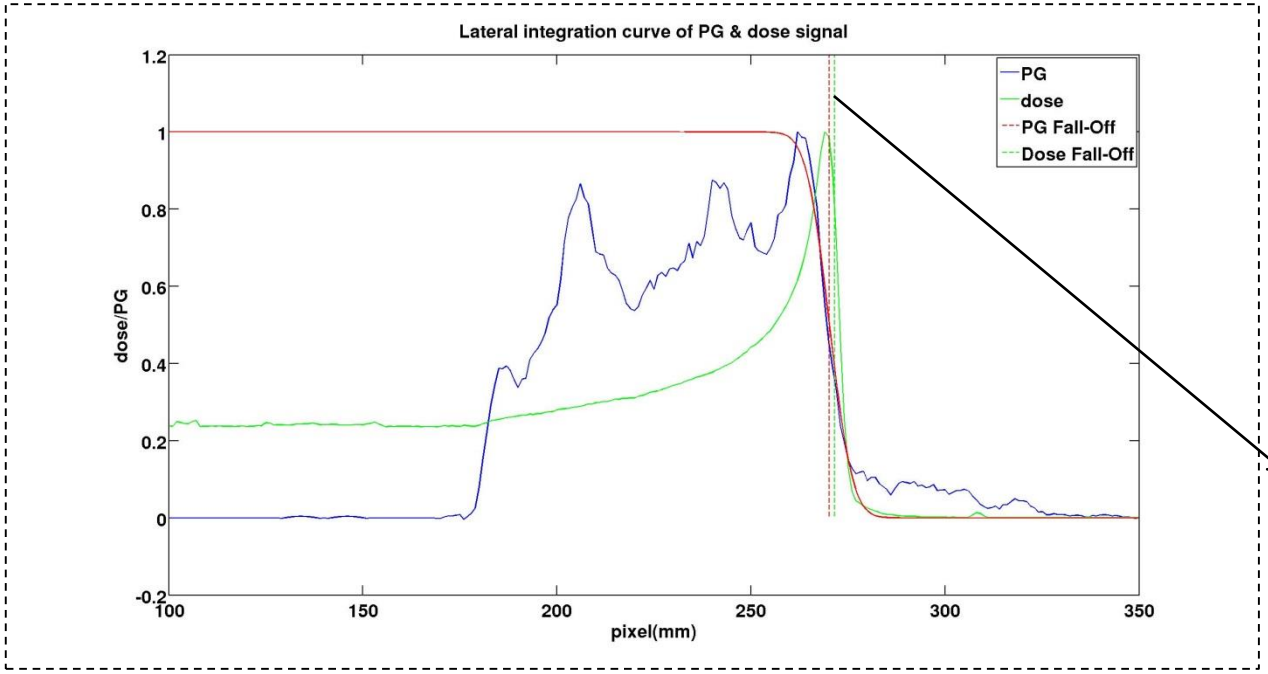
Lateral integration of PG & dose signal

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

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

Introduction

- Ideal PG & dose profile



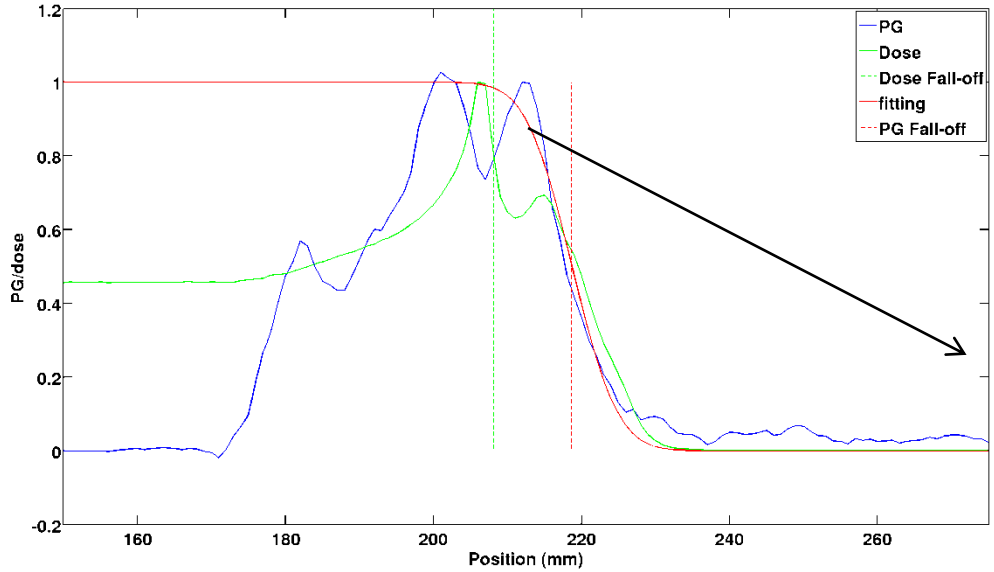
$dR = -1.30\ mm$

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



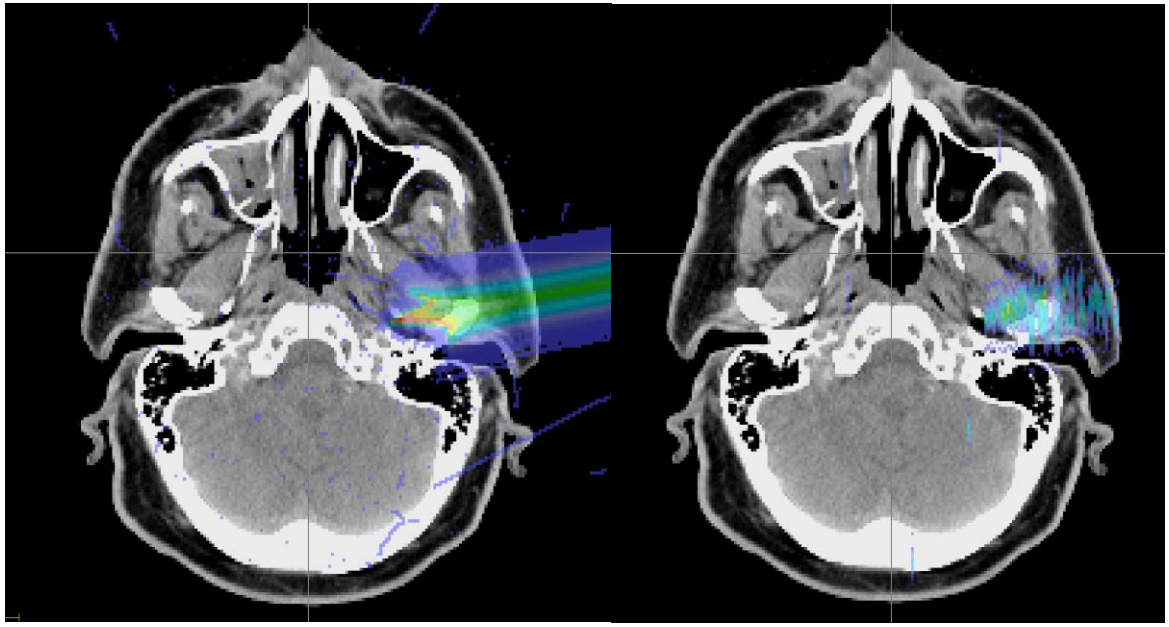
$dR = -8.6\ mm$

Lateral integration of PG & dose signal

Introduction

- Reason

Tissue inhomogeneity (bone/air in beam path)



Dose delivery PG emission

Introduction

- The PG-dose correlation of individual pencil beam (called subPB in the following) 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 subPBs

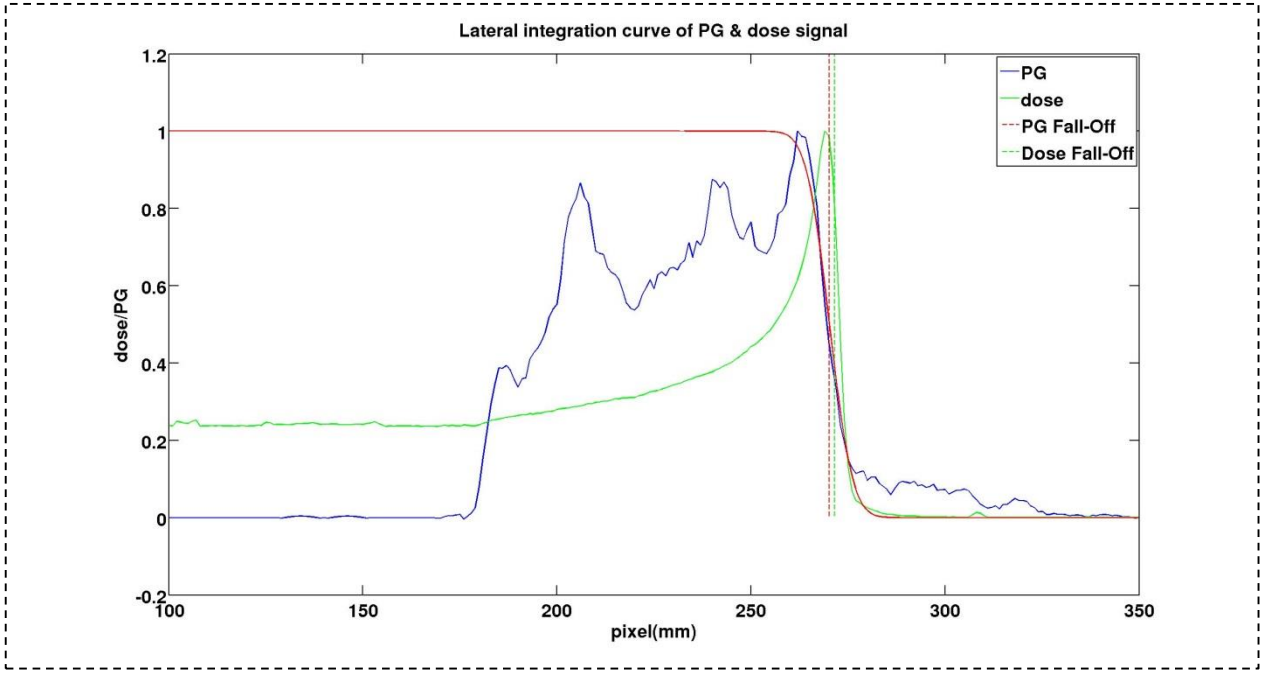
Criteria:

- 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:

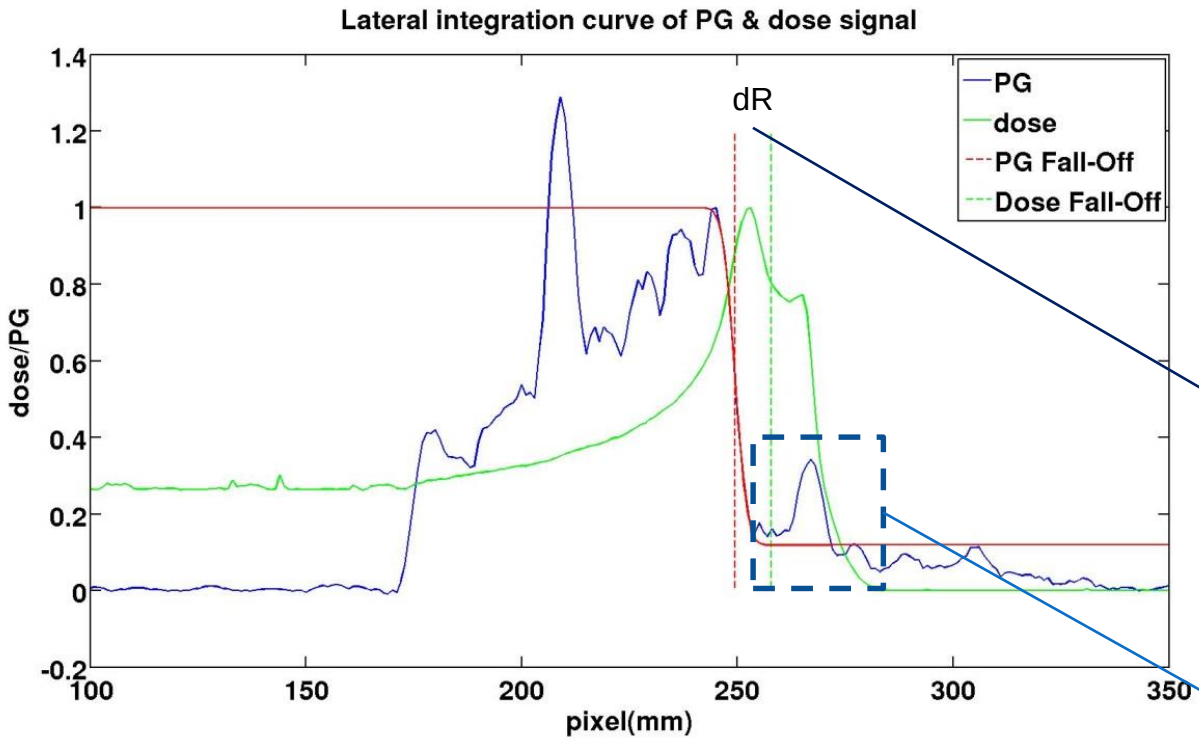
Ideal case:



Method

- Example:

  Poor correlation case 1:



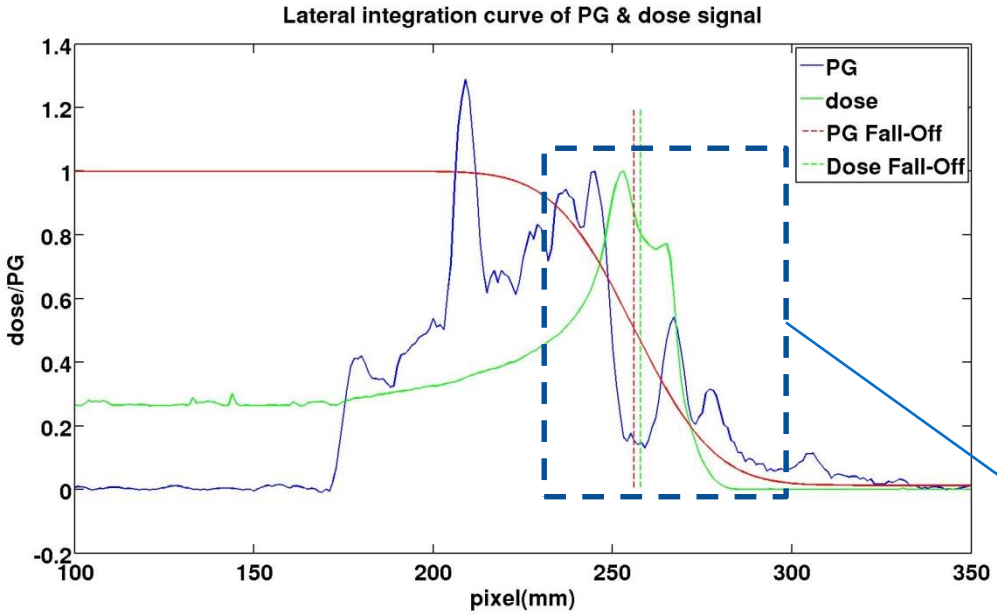
Large dR relates to poor correlation directly

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 subPBs
2. Improve the initial treatment plan while maintaining the quality of plan

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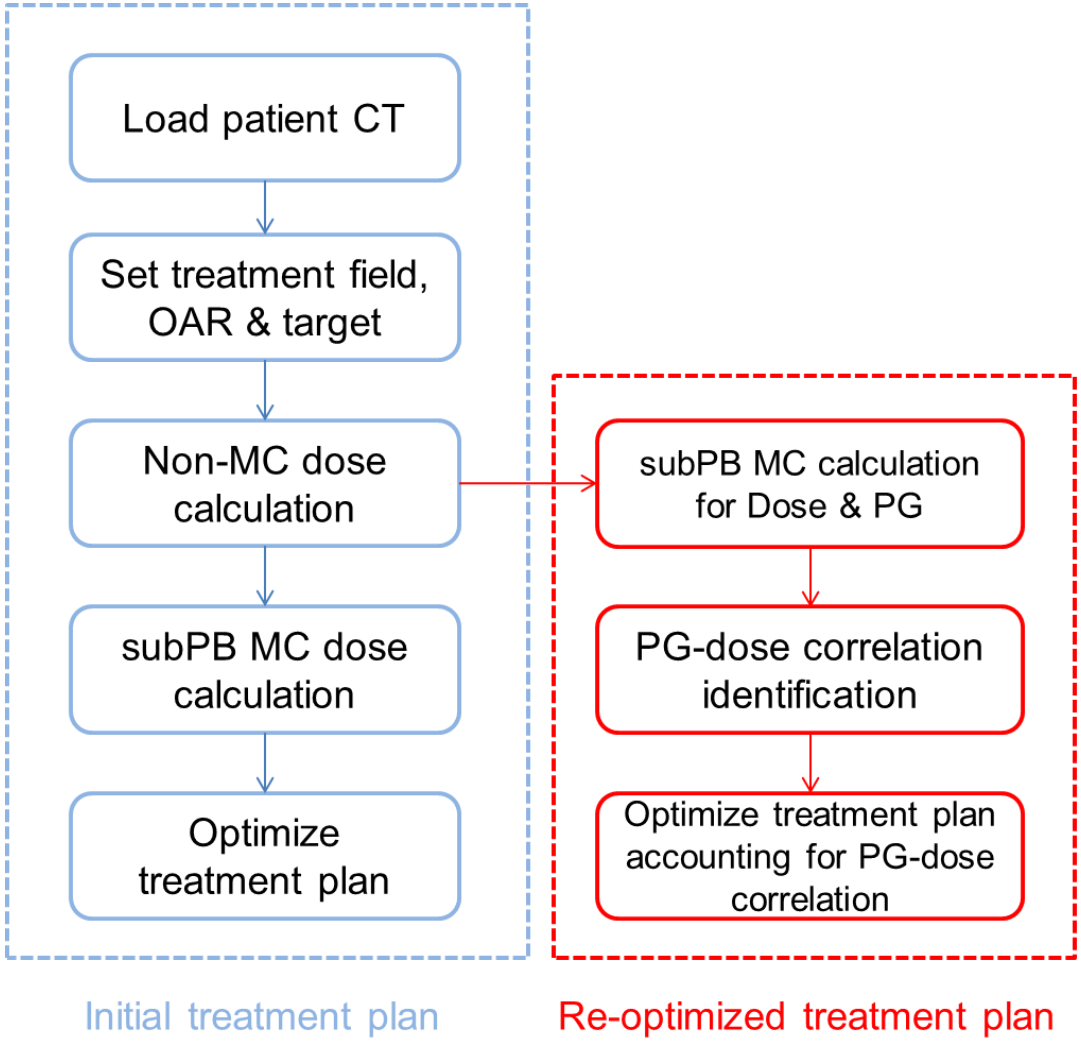
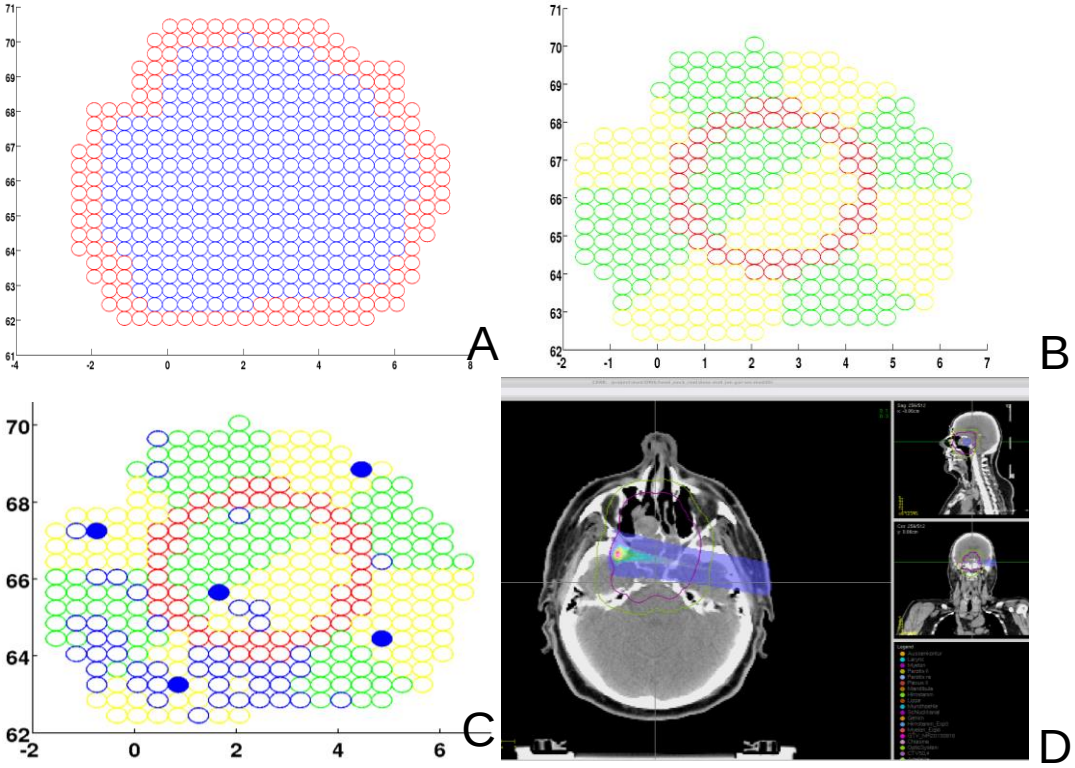
General workflow of CERR TPS and our improved TPS:



Method

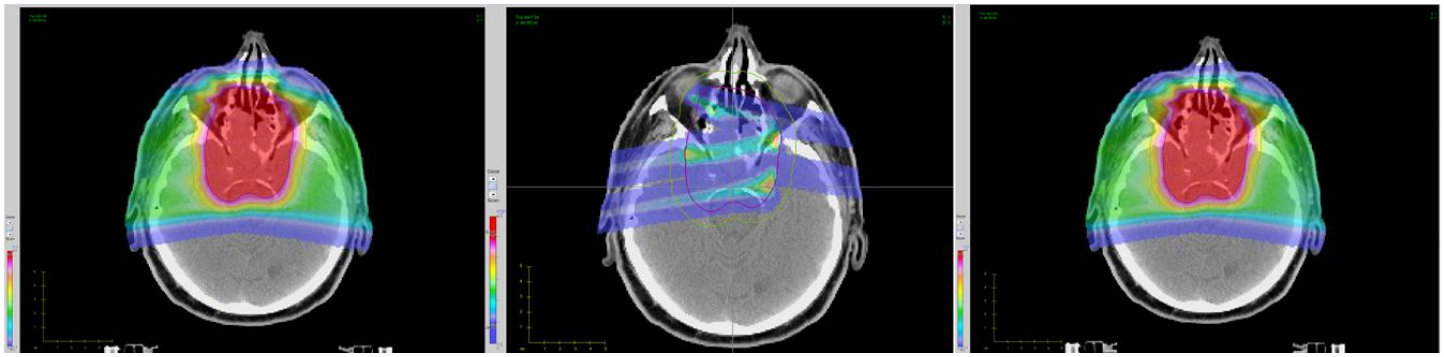
- Boost few subPBs which have the best PG-dose correlation



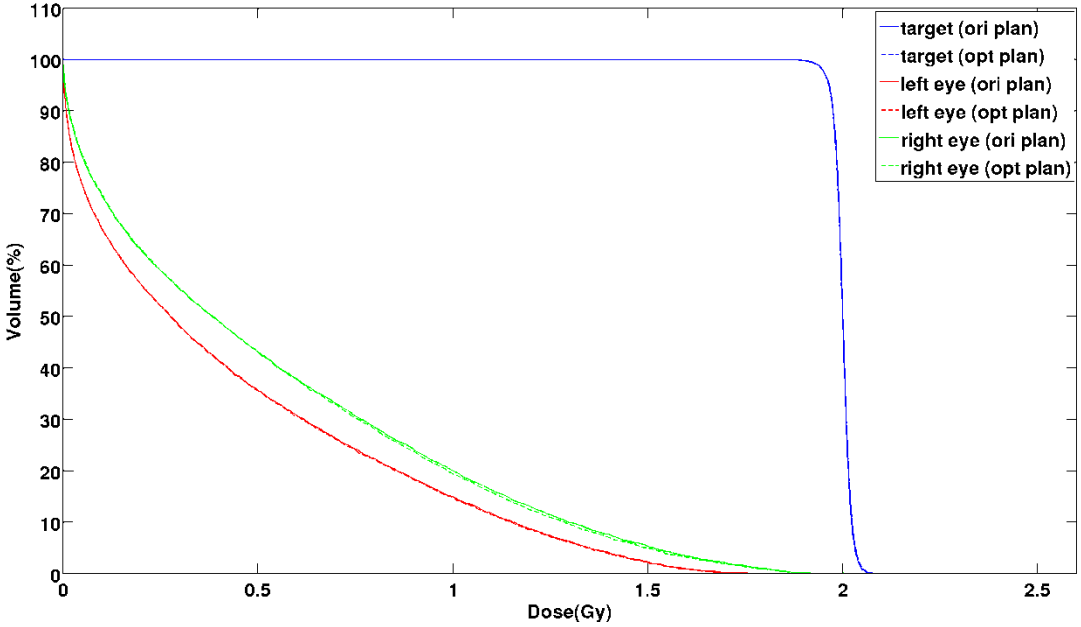
Result

- Dose delivery
- PG-dose correlation

Dose delivery



Patient 1



Result

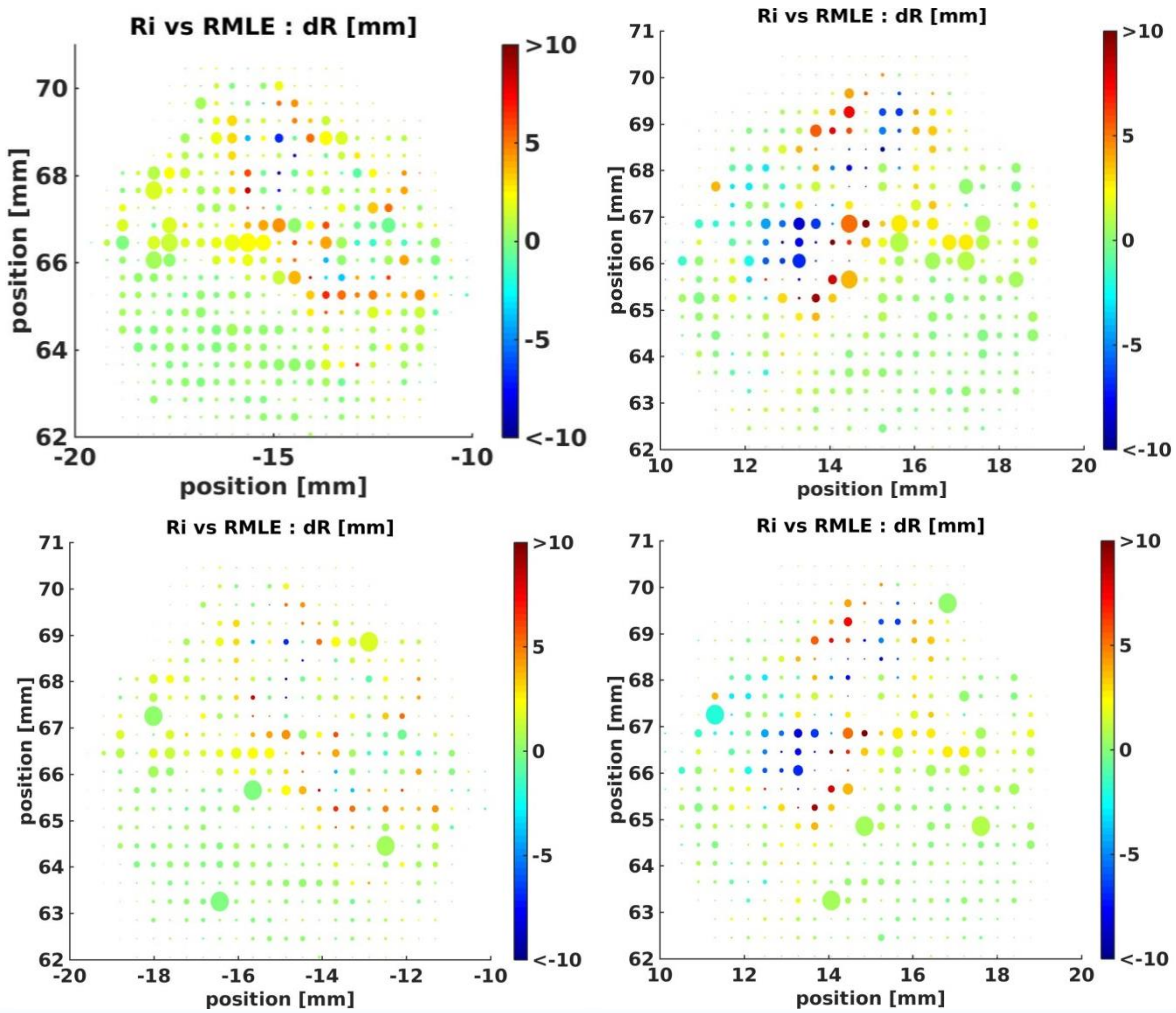
- Dose delivery
- PG-dose correlation

PG-dose correlation

Beam's eye:

The color shows the PG-dose correlation and

The spot radius is linearly proportional to the proton number



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 subPBs 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 subPBs in the new plan could provide reliable in-vivo proton range verification

Future work

- MC treatment plan is time-consuming, especially when more protons are needed to generate enough PG emission
- Detection devices signal is different from PG emission
- Robustness of PG-dose correlation considering anatomical change and different uncertainties
- Combine state-of-the-art CBCT, DECT

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

Thank you!