HollandPTC
Protonen Therapie Centrum

Proton Therapy Robustness Projects

1. Method development for fast evaluation of clinical proton therapy plan quality (MEP);
2. Coupled Polynomial Chaos Expansion and Reduced Order Modeling methodologies for proton therapy applications (MEP, BEP);
3. Robustness recipes for proton therapy treatment planning (MEP)

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1. Method development for fast evaluation of clinical proton therapy plan quality (MEP)

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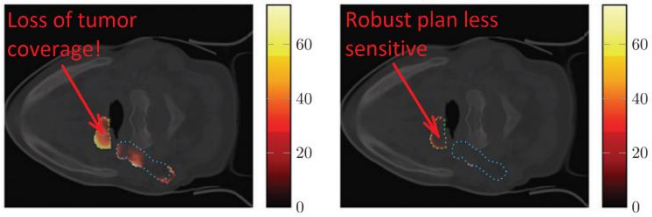
Protons' better ability over conventionally used photons to deposit dose exactly at the tumor comes at the price of increased sensitivity to uncertainties such as patient positioning or proton range. Proton plans therefore have to be tested for robustness against these uncertainties to assure their adequacy. Modern commercial treatment planning systems offer tools to perform robustness analyses for a limited number of potential error scenarios. This project focuses on the development of guidelines for the use of these tools in the clinic. The aim is to use advanced uncertainty quantification methods (based on so called Polynomial Chaos Expansion) to identify which error scenarios should be used in order to derive computationally affordable, yet meaningful and general metrics of robustness.



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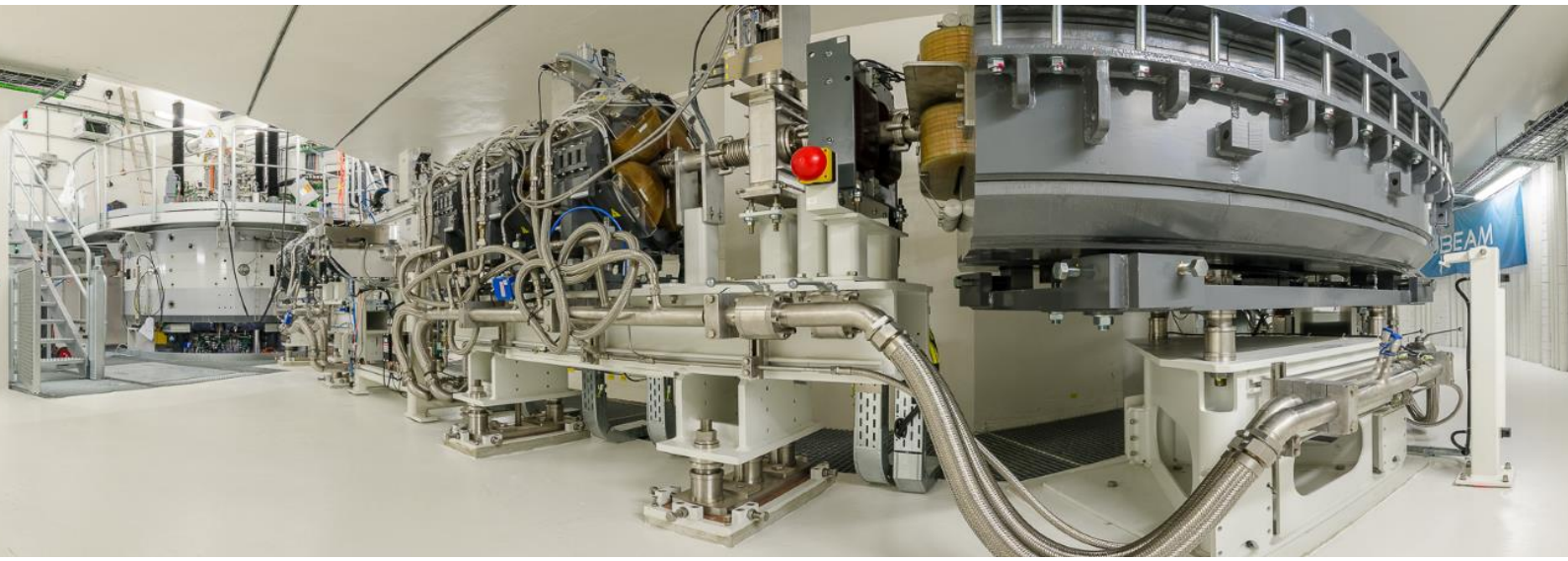

2.Coupled Polynomial Chaos Expansion and Reduced Order Modeling methodologies for proton therapy applications (MEP, BEP)

Handling uncertainties in proton therapy planning is a key challenge to ensure the best treatment for cancer patients. The main difficulty is that proton dose distributions are sensitive to all sources of uncertainties, such as patient positioning, proton range, internal organ motion or progressive anatomical changes (like weight loss or tumor shrinkage). To calculate the dosimetric effects of these uncertainties the dose has to be recalculated for every possible error scenario, which is computationally expensive, and currently prohibitive in a clinical setting.
The goal of this project is to develop and investigate coupled Polynomial Chaos Expansion (PCE) and Reduced Order Modelling (ROM) methods for the improvement of proton therapy treatment planning. Our recent work has already shown and PCE methods provide a fast and accurate way to predict the dosimetric effects of patient positioning and range uncertainties. However, in these works PCE models of the voxel level doses were built, resulting in a large number of PCE coefficients (in the millions), with a relatively high memory burden. ROM methods have the ability to capture correlations between quantities and identify the fundamental modes of changes.

Thus, by first decomposing the dose distribution corresponding to different error scenarios with ROM (e.g. using Principal Component Analysis or Singular Value Decomposition), and consequently using PCE for only the most important modes could very significantly reduce memory requirements and speed up calculations. Such a methodology thus would enable fundamentally novel ways for handling of uncertainties with advanced treatment planning methods (probabilistic optimization), with the incorporation of complex anatomical uncertainties, and ultimately could pave the way for immediate dose calculations, necessary for adaptive treatments.

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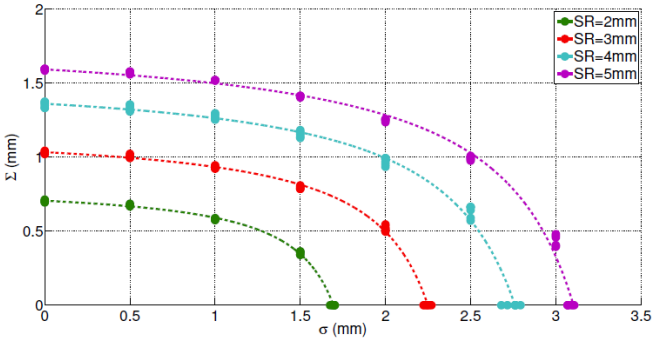
3.Robustness recipes for proton therapy treatment planning (MEP)

In modern proton therapy treatment planning so-called robust optimization approaches are used to ensure that the generated treatments are sufficiently robust against uncertainties. In robust optimization, a limited number of potential error scenarios are included in deriving the plan, such that it fulfills all treatment goals in all the included scenarios. In reality however, there are infinitely many possible error scenarios in which the patient can be, and the outcome of the treatment can only be determined probabilistically, e.g. by calculating what the probability of giving enough dose to the target is. Hence it is important to know what the connection between the error scenarios included in the robust optimization and the actual probabilistic outcome is. Our recent work has shown that using Polynomial Chaos Expansion (PCE) methodology it is possible to quickly and quantitatively evaluate the effects of uncertainties. Consequently so-called "robustness recipes" could be derived (shown in the figure), giving which error scenarios must be used in the robust optimization such that the resulting plan has the desired probabilistic outcome, given known probability distributions for patient positioning and proton range errors.



So far however, this was done by only taking into account the coverage probability of the tumor. The goal of this project is to expand this work by also including organs at risk in the recipe formulations, furthermore to address numerous outstanding limitations of the current approach

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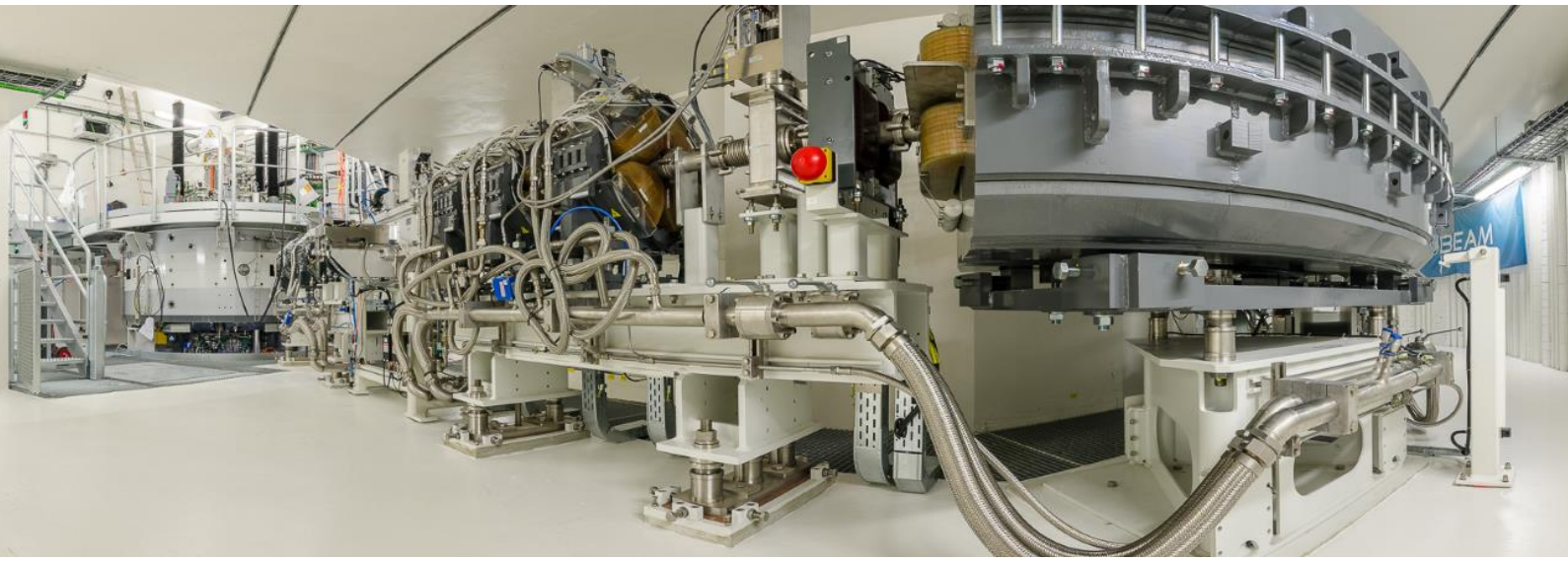

(such as the correct interpretation of range errors, expanding and refining the PCE methodology, and potentially including complex anatomical uncertainties).

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