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Quantification of Uncertainties in a Model-Based Iterative Reconstruction Algorithm for Proton Computed Tomography

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Proton computed tomography (pCT) is a medical imaging modality with the potential to improve the accuracy of treatment planning for proton-beam radiotherapy. It produces a three-dimensional image of the relative stopping power (RSP) distribution inside an object, given a list of positions and directions of protons before and after passing through the object, along with the corresponding energy losses. The underlying tomographic reconstruction task can be understood as a least-squares problem, and solved by a model-based iterative process.
Various uncertainties due to calibration errors, measurement errors or errors in the track reconstruction process may arise as inputs to the RSP reconstruction. It is crucial to consider the influence of these uncertainties in the modeling of the reconstruction and in the process of designing the tracking calorimeter as a long-term scope of this work. For this purpose, our aim is to investigate on the effect of local perturbations by means of a sensitivity analysis as well as on the effect of random inputs with the help of strategies for uncertainty propagation in a probabilistic description.
In this work, we will present first investigations for both types of uncertainties. Regarding local perturbations, one may observe that the algorithmic description of the reconstruction process is only piecewise differentiable. Jumps arise from the discrete computation of the set of voxels intersected by a proton path. To represent uncertainties in the proton positions in front of the calorimeter, we model the positions as normally distributed random variables, and employ sampling strategies for propagation. Uncertainties arising from the calibration of the magnets may be modelled with a moderate number of random variables. Here, we make use of discrete projection methods to avoid the computationally high costs of sampling. Uncertainties in the measurements may be specifically adressed in modeling when using an extended most likely path formalism. The modeling and propagation of uncertainties allows us to assess the overall impact of this approach on the quality of the reconstruction.

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