Master thesis on ion imaging

The Chair of **Experimental Physics – Medical Physics** in the Faculty for Physics of the *Ludwig-Maximilians-Universität München* (LMU Munich) is offering Master theses to join the *Deutsche Forschungsgemeinschaft* (DFG) project "Hybrid ImaGing framework in Hadrontherapy for Adaptive Radiation Therapy (High-ART)".

Scientific context

In ion beam therapy the empirical calibration of the X-ray CT image introduces inaccuracies into the treatment planning. The promise of ion imaging is to potentially eliminate these inaccuracies by replacing the X-ray CT image with the **ion CT image** based on **tomographic image reconstruction** of the ion radiographies [1]. Numerical algorithms are based on the model of the ion radiography as line integral along the estimation of the ion trajectory [2]. However, this model (i.e., the forward-projection model) is not perfectly consistent to the measurement (i.e., the ion radiography), mostly due to the Multiple Coulomb scattering of the ions. Depending on the detector configurations (**Figure 1**), these intrinsic inconsistencies in clinical data can result in the same order of magnitude as the calibration inaccuracies that are intended to be eliminated [3].

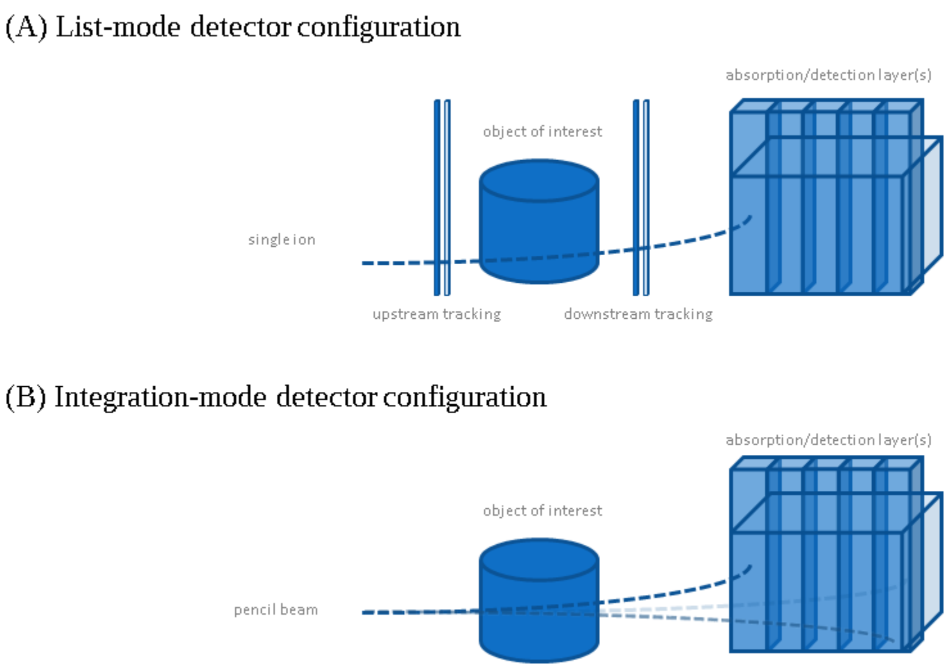

Figure 1. Illustration of the different detector configurations for ion imaging. The list-mode detector configuration is based on the synchronization of a thick absorber (e.g., range telescope or energy caloritmeter) with a tracking system for single ions typically consisting of thin semiconductor trackers upstream and downstream the object of interest (A). The integration-mode detector configuration, intended for pencil beams, is composed by only the absorption detector without tracking system (B).

Project

The fundamental aim of the project is the minimization of these **intrinsic inconsistencies** by making the **forward-projection model** more consistent to the **ion radiography**. The Multiple Coulomb scattering model can be described as a bi-variate Gaussian distribution with increasing standard deviation along the initial ion direction (i.e., the direction in air prior to scattering into the object of interest) [4]. Depending on the detector configurations, this model can be embedded in the estimation of the ion trajectory. In particular, for the list-mode detector configuration, the statistical description of the uncertainties of the ion trajectory is constrained by the ion tracking upstream and downstream the object of interest, thus resulting in the so called “**scattering spindle**”. Whereas for integration-mode detector configuration, the statistical description of the uncertainties of the pencil beam trajectory is referred to as a “**scattering cone**” (**Figure 2**).

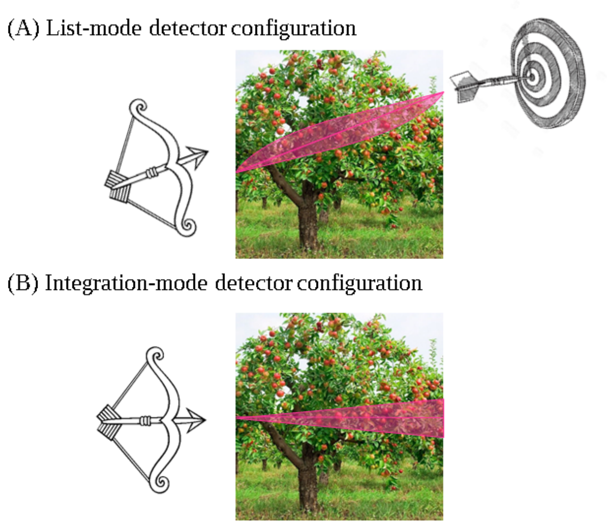

Figure 2. Illustration of the uncertainties (in pink) of the ion trajectory for different detector configurations. The “scattering spindle” for the list-mode detector configuration follows the most probable ion trajectory inside the object of interest (A), derived from the tracking and energy/range information based on the Bayes formalism of the maximum likely path [2]. The “scattering cone” for the integration-mode detector configuration, calculated from the energy/range information, is centered across the nominal direction of the pencil beam (B).

Master theses

A Master thesis is proposed to further investigate this approach to tomographic image reconstruction for integration-mode detector configuration based on Monte Carlo simulations of clinical data, thus complementing the preliminary investigation based on analytical simulations of anthropomorphic phantoms [5]. Another Master thesis is proposed to extend this approach to tomographic image reconstruction to list-mode detector configuration in both Monte Carlo and analytical simulations.

References

[1] Meyer, S., Kamp, F., Tessonnier, T., Mairani, A., Belka, C., Carlson, D. J., Gianoli, C., & Parodi, K. (2019). Dosimetric accuracy and radiobiological implications of ion computed tomography for proton therapy treatment planning. *Physics in medicine and biology*, 64(12), 125008.

[2] Meyer, S., Pinto, M., Parodi, K., & Gianoli, C. (2021). The impact of path estimates in iterative ion CT reconstructions for clinical-like cases. *Physics in Medicine and Biology*, 66(9), 095007.

[3] Gianoli, C., Göppel, M., Meyer, S., Palaniappan, P., Rädler, M., Kamp, F., ... & Parodi, K. (2020). Patient-specific CT calibration based on ion radiography for different detector configurations in 1H, 4He and 12C ion pencil beam scanning. *Physics in Medicine and Biology*, 65(24), 245014.

[3] Gianoli, C., Meyer, S., Magallanes, L., Paganelli, C., Baroni, G., & Parodi, K. (2019). Analytical simulator of proton radiography and tomography for different detector configurations. *Physica Medica*, 59, 92-99.

[5] C. Seller Oria, S. Meyer, E. De Bernardi, K. Parodi and C. Gianoli. A Dedicated Tomographic Image Reconstruction Algorithm for Integration-Mode Detector Configuration in Ion Imaging. *In Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2018 IEEE.*

Requirements

Academic records are requested for application. Specific requirements include:

- Good understanding of the physics of medical imaging
- Proficiency in coding and documentation standards, Monte Carlo simulations and programming languages, preferably C/C++, Python, MATLAB and related imaging libraries and machine learning tools, along with Linux and Windows OS
- Interest in artificial intelligence

Contacts

- (Dr. Chiara Gianoli) Chiara.Gianoli@physik.uni-muenchen.de
- (Prof. Dr. Katia Parodi) Katia.Parodi@physik.uni-muenchen.de