Report of the 1st semester

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PhD Program: Particle and Nuclear Physics

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Title of Thesis: Development of proton computed tomography applied in hadron therapy

Introduction

Hadron therapy is a very promising cancer treatment that utilises the radiation of ionizing particles. When such a particle enters a medium, it deposits its energy due to interactions, such as Coulomb scattering. The Water Equivalent Path Length (WEPL) of the beam in the respective medium can be defined by the Bragg curve. The WEPL expresses how much the material attenuates a beam of radiation in comparison to water.

The peak of the Bragg curve can be tuned finely with the energy of the beam. As a consequence of this, there is a great need for accurate dosage planning. The currently used and most widespread diagnostic method is X-ray CT; however, the conversion to the hadron beam results in significant uncertainty. The Bergen Proton CT Collaboration aims to address this issue via the development of a novel proton CT detector system, based on the ITS detector of the CERN ALICE Experiment.

The aim of my research is the development of an imaging method that has not yet been previously applied in medical imaging. This method is called the Richardson-Lucy algorithm that is based the Maximum Likelihood - Expectation Maximization approach [1,2]. The implementation of this algorithm employs the energy loss of protons and my ultimate goal is to adapt and refine it for clinical usability, contributing to the Bergen Proton CT Collaboration [3].

Description of research work carried out in the current semester

I worked on a framework that uses the Richardson-Lucy algorithm for image reconstruction with protons. I used simulations I made with Geant4 and GATE [4], since the detector of the Bergen Proton CT Collaboration is still in the making, thus I do not yet have access to real data. These simulations are very time-consuming, therefore I applied paralelization techniques.

I was working on the Most Likely Path calculation of the protons and optimizing the runtime of the reconstruction with the algorithm. Two phantoms were already in use for the evalution of this framework, the Derenzo and the CTP404 phantoms [5,6] (to evaluate the spatial and the Relative Stopping Power (RSP) resolution, respectively). The part of the framework that is responsible for the RSP reconstruction is a C++ code, which is speeded using GPU (CUDA). This was carried out in the Wigner Scientific Computing Laboratory (WSCLAB) on Nvidia GTX 1080 Ti GPU.

This semester I started working on carrying out the evaluation of the spatial resolution with a third type of phantom, the CTP528. A conventional measure for spatial resolution is the Modulation Transfer Function (MTF), more precisely its 10% value. For this, I developed a short program that executes an automatized evaluation. This takes the intensity profiles of the RSP map at the different segments of the inserts of the phantom with different radii and averages on them to get an averaged intensity profile. Finding the maxima and minima of the intensity profile makes it possible to calculate a contrast, of which the calculation of the MTF is feasible [7].

Three different setups (ideal, silicon pixel detector and silicon strip detector) were compared with each other and the ground truth RSP values. In the idealized case, there were no added simulated measurement errors; the silicon pixel detector was modeled after the design of the Bergen proton CT detector, while the silicon strip detector was modeled after LLU/UCSC Phase II Scanner design [8]. The latter two designs both had 3 water equivalent mm resolution in WEPL. The average relative RSP difference for the listed materials was found to be 0.28% for the ideal, 0.85% for the silicon pixel, and 1.31% for the silicon strip setups after processing 3.7 million protons.

Publications

G. Bíró, Á. Sudár, Zs. Jólesz, G. Papp, G.G. Barnaföldi. *Proton Computed Tomography Based on Richardson-Lucy Algorithm.* ArXiv:2212.00126

B. Dudás, Zs. Jólesz, G. Bíró, G. Papp, G.G. Barnaföldi. *Reconstruction of proton relative stopping power with a granular calorimeter detector model.* International Journal of Modern Physics A, Special Issue: Zimányi School 2023.

Studies in current semester

When the semester started, I was still in CERN (Geneva, Switzerland) on the Summer Student Programme. There I was researching beam background detection of the ITS detector in the ALICE experiment. After I came home I took 3 courses in this semester:

- Selected chapters from experimental high-energy physics (FIZ/2/117)
- Phase structure of strongly interacting matter (FIZ/2/024)
- Preclinical models in cancer research (FIZ/3/082)

I scored grade 5 from the first two, the last one is still under evaluation.

Conferences in current semester

- V4 – High Energy Physics, 28-30.10.2024, Warsaw (Plenary talk)
- 24th Zimányi Winter School, 2-6.12.2024, Budapest (Poster and flash talk – here I earned the prize of the Best Poster and Flash Talk)

Educational activities in current semester

Classical physics laboratory (fizlab2f19la)

Modern computatonal methods in physics 2 (korszam2f19ea)

References

[1] Leon B Lucy. An iterative technique for the rectification of observed distributions. Astronomical Journal, Vol. 79, p. 745 (1974), 79:745, 1974.
[2] William Hadley Richardson. Bayesian-based iterative method of image restoration. JoSA, 62(1):55–59, 1972.
[3] Johan Alme, Gergely Gábor Barnaföldi, Rene Barthel, Vyacheslav Borshchov, Tea Bodova, Anthony Van den Brink, Stephan Brons, Mamdouh Chaar, Viljar Eikeland, Grigory Feofilov, et al. A high-granularity digital tracking calorimeter optimized for proton CT. Frontiers in Physics, 8:568243, 2020.
[4] David Sarrut, Thomas Baudier, Damian Borys, Ane Etxebeste, Hermann Fuchs, Jan Gajewski, Loïc Grevillot, Sébastien Jan, George C Kagadis, Han Gyu Kang, et al. The OpenGATE ecosystem for Monte Carlo simulation in medical physics. Physics in Medicine & Biology, 67(18):184001, 2022.
[5] SE Derenzo, TF Budinger, JL Cahoon, RH Huesman, and HG Jackson. High resoluti-

on computed tomography of positron emitters. IEEE transactions on Nuclear Science, 24(1):544–558, 1977, doi:10.1097/00004728-198112000-00086.
[6] Blake Schultze, Yair Censor, Paniz Karbasi, Keith Schubert, and Reinhard Schulte. An improved method of total variation superiorization applied to reconstruction in proton computed tomography. IEEE Transactions on Medical Imaging, PP, 03 2018, doi:10.1109/TMI.2019.2911482.
[7] Jarle Rambo SØlie, Lennart Volz, Helge Egil Seime Pettersen, Pierluigi Piersimoni, Odd Harald Odland, Dieter Röhrich, Håvard Helstrup, Thomas Peitzmann, Kjetil Ullaland, Monika Varga-Kofarago, et al. Image quality of list-mode proton imaging without front trackers. Physics in Medicine & Biology, 65(13):135012, 2020, doi:10.1088/1361-6560/ab8ddb.
[8] Johnson et al., 2016.