Report of the 3rd semester

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PhD Program: Particle and Nuclear Physics

Supervisors: Gábor Bíró, Gábor Papp

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

During the current semester, I actively disseminated my research results at several international scientific conferences. I presented my work at the *Fifth MODE Workshop* and at the *Particles and Plasmas* conference, where I received poster prizes at both events. These opportunities provided valuable feedback on my work and helped strengthen international visibility and connections.

In addition to conference participation, I was involved in science outreach and education. I held lectures presenting my research at the Eötvös Science Camp (Eötvös TermTudTábor) and at the Balaton Summer School, introducing students to the principles of proton and ion imaging as well as detector-based reconstruction methods.

As part of my involvement in large-scale experimental collaborations, I traveled to CERN, where I completed detector shift trainings and participated in data-taking shifts within the ALICE experiment. This work contributed to the operation of the detector system and further strengthened my hands-on experience with complex high-energy physics instrumentation and data acquisition procedures. Later on this semester, I also participated in the ALICE Week at CERN.

I was also involved in university-level teaching activities. During the semester, I held a *Classical Physics* laboratory course and delivered two lectures for the course *Advanced Computational Methods.*

Furthermore, I traveled to China to explore and establish potential research collaborations. During visits to research institutions in Wuhan and Lanzhou, I held three seminars together with my supervisor, presenting our current research activities. In Lanzhou, I was also given a guided tour of

the local hadron therapy center, providing valuable insight into clinical applications of ion beam therapy and imaging.

During this semester, I was awarded the EKÖP Scholarship, under which I began a new research line focusing on imaging methods for hadron therapy using helium and carbon ion beams. This work aims to extend existing proton-based imaging approaches to heavier ions, with the goal of improving image quality and treatment verification. I am currently preparing a scientific publication based on the results obtained so far.

Publications

G. Bíró, Á. Sudár, Zs. Jólesz, G. Papp, G.G. Barnaföldi. *Proton Computed Tomography Based on Richardson-Lucy Algorithm*. ArXiv:2212.00126v2

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

I took one course in this semester, where I scored grade 3:

- Experimental methods in particle physics II. (FIZ/2/004E)

Conferences in current semester

- Fifth MODE Workshop on Differentiable Programming for Experiment Design, 08-13.06.2025, Crete (Poster + Talk) – 3rd Poster Prize
- Hungarian-German WE-Heraeus Seminar – Particles and Plasmas in Strong Fields, 22-26.06.2025, Dresden & Görlitz (Poster) – Best Poster Prize

Educational activities in current semester

- Classical physics laboratory (fizlab2f19la)
- Modern computational 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.