2025 Helmholtz – OCPC – Program

for the involvement of postdocs in bilateral collaboration projects

PART A

Title of the project:

Second Generation Detector System for PROTECT (Proton Theranostics and Early-Stage Cancer Tomography)

Helmholtz Centre and/or institute:

Karlsruhe Institute of Technology (KIT), Institute of Biomedical Engineering (IBT)

Project leader:

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Description of the project (max. 1 page)**:**

Introduction

Image-guided adaptive proton therapy (IGAPT) is an advanced cancer treatment modality that combines the high precision of proton therapy with the ability to adjust treatment plans daily to reflect changes in tumor size, shape and location. Currently, IGAPT relies on repeated X-ray computed tomography (XCT) scans that expose patients to significant doses of ionizing radiation, increasing the risk of radiotoxicity and secondary malignancies.

The PROTECT aims to eliminate the need for multiple XCT scans by integrating proton radiography (pRad) into clinical IGAPT workflows. Compared to a single XCT snapshot, pRad offers a tenfold dose reduction, significantly reducing the risk of radiation-related complications. The underlying imaging technology developed in PROTECT can be applied as a low-dose diagnostic tool via proton CT (pCT), expanding the scope of proton-based imaging for both clinical and research applications.

Current Challenges

Existing clinical prototypes have readout rates of about 3 MHz - sufficient for static targets, but insufficient for moving tumors or rapid diagnostic applications. Achieving the goal of online IGAPT and low-dose proton diagnostics therefore requires significant improvements in the speed and sensitivity of residual energy detectors, which are the cornerstone of proton imaging systems.

Research and Development Focus

The primary R&D objective of this project is to design and validate a next-generation monolithic scintillator-based residual energy detector capable of readout rates up to 10 MHz. The appointed postdoctoral researcher will:

1. **Simulation and design**
   a. Use Monte Carlo simulations to optimize the detector geometry and materials.
   b. Ensure that the electronics and data acquisition systems can handle high data rates without degrading image quality.
2. **Prototype Assembly and Commissioning**
   a. Participate in hardware assembly and commissioning in close collaboration with other team members.
   b. Integrate software for data acquisition and control of the newly designed detector.
3. **Fast image reconstruction**
   a. Refine reconstruction algorithms to enable online imaging within a clinical workflow, i.e. while the patient remains in the treatment room.

Project Infrastructure

The project makes use of the advanced infrastructure at IBT-KIT, including a dedicated electrical engineering laboratory, the PROTECT test stand, and access to CPU/GPU clusters for computational modeling. The project cooperates closely with the German Cancer Research Center (DKFZ) and the Heidelberg Ion Therapy Center (HIT), where a first-generation prototype for proton and helium imaging is currently in operation. The postdoc will also benefit from the educational resources of IBT-KIT.

Expected Outcome

Second-Generation Residual Imaging Detector: Completion of a high-performance residual energy detector prototype capable of meeting the 10 MHz readout requirement, thereby enabling proton imaging of the moving targets and future diagnostic application.

Description of existing or sought Chinese collaboration partner institute (max. half page)**:**

This project aims to establish a collaboration between IBT-KIT and the Shanghai Proton and Heavy Ion Center (SPHIC). SPHIC is one of the leading institutes for advanced radiation oncology in China, integrating state-of-the-art clinical facilities for proton and heavy ion therapy. SPHIC has a strong focus on translational research, which aligns well with the mission of the PROTECT project to develop next-generation proton imaging solutions for real-time IGAPT.

Through this collaboration, SPHIC and KIT aim to leverage each other's expertise and infrastructure for joint research and development. Specifically, SPHIC offers clinical expertise and access to state-of-the-art beam delivery systems, including synchrotron-based proton and carbon ion beams - ideal for evaluating and validating the novel proton imaging approach proposed in PROTECT. KIT's Institute of Biomedical Engineering (IBT), in turn, brings a wealth of experience in detector design, Monte Carlo simulation, and high-speed data acquisition, providing critical support for prototype assembly, software integration, and image reconstruction methods.

Both partners envision a synergistic workflow spanning basic research, clinical testing, and eventual technology transfer. The collaboration will include joint experiments at SPHIC's treatment beamlines to validate the new residual energy detector prototype and software solutions under realistic clinical conditions. This inter-institutional effort will also facilitate training opportunities for young scientists and postdoctoral fellows in cutting-edge imaging and therapy technologies and foster sustainable bilateral collaborations.

By combining SPHIC's clinical insights with KIT's research strengths, the partnership aims to accelerate the development of safe, effective, and low-dose proton imaging techniques - thereby expanding the application of particle therapy in China and worldwide.

Required qualification of the postdoc:

- PhD in Medical Physics/Computer Science/Biomedical Engineering
- Experience with Monte Carlo Simulation (GEANT4/Topas or FLUKA), programming (C, C++, Python, LabVIEW), experimental work with proton/ion beams.
- Language requirement: fluent in English