# 2025 Helmholtz – OCPC – Programme

## for the involvement of postdocs in bilateral collaboration projects

**PART A**

**Title of the project:**

AI Optimization for PETRA IV Storage Ring

**DESY Division & Group**

M-MPY

**Project leader/supervisor:**

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

The 4th-generation light source PETRA IV is a state-of-the-art facility designed to produce ultra-bright X-rays with an emittance below 20 picometers, enabling groundbreaking research for the global scientific community. However, designing and optimizing such advanced accelerators involves complex nonlinear dynamics, beam stability challenges, and strict operational constraints, requiring innovative solutions.

To address these challenges, we propose leveraging the latest developments in AI and deep learning to optimize beam dynamics, nonlinear lattice configurations, and orbit corrections while maintaining operational constraints and minimizing costs.

The following table summarizes AI methods successfully applied in accelerator design and operations, with their relevance to PETRA IV:

| | | |
|---|---|---|
| Reinforcement Learning (RL) | Real-time orbit correction | Used in CERN's LHC, SLAC's LCLS-II |
| Gaussian Process Regression (GPR) | Magnet misalignment modeling | Beam orbit correction in CERN's LHC |
| Neural Networks (NN) | Beam diagnostics and orbit prediction | Used in SuperKEKB (Japan) |
| Autoencoders | Anomaly detection in orbit distortions | Used at Fermilab for beam stability |
| Genetic Algorithms (GA) | Optimizing multi-magnet settings | NSLS-II (Brookhaven Lab) |

The project will focus on two major areas:

1. Nonlinear Optimization of Dynamic & Momentum Apertures
    - Develop AI-driven physics-informed neural networks (PINN) for nonlinear lattice modeling.
    - Implement Taylor-Map-based Polynomial Neural Networks (TM-PNN) and Deep Lie-Map Networks (DLMN) to optimize the PETRA IV lattice.
    - Enhance injection efficiency and beam lifetime by optimizing Dynamic Aperture (DA) and Momentum Aperture (MA).
    - Utilize Bayesian Optimization (BO) and Bayesian Algorithmic Execution (BAX), which significantly outperforms traditional Genetic Algorithms (MOGA).
2. AI/ML Research for Accelerator Science (Open-ended Exploration)
    - Contribute to the development of modern AI/ML algorithms for particle accelerator applications.
    - Explore Large Language Models (LLMs) and Generative AI (GANs, Transformers, Diffusion Models, Autoencoders) for data-driven and model-independent optimization.
    - Develop pattern recognition algorithms for beam stability, orbit correction, and performance enhancement.
    - Work with both numerical simulations and experimental data from PETRA IV/III.

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

- Tsinghua University
- Peking University
- Institute of High Energy Physics, Chinese Academy of Sciences
- Shanghai Advanced Research Institute, Chinese Academy of Sciences
- Institute of Modern Physics Chinese Academy of Science

**Required qualification of the postdoc:**

We are seeking **highly motivated** candidates with:

✅ A **PhD in Physics, Electrical Engineering, Computer Science, or a related field** (preferably in Accelerator Physics or AI/ML).

✅ Strong background in **AI/ML methods, optimization algorithms, and numerical simulations**.

✅ Experience with **particle accelerators**, beam physics, or experimental data analysis is highly desirable.

✅ Proficiency in **Python, TensorFlow/PyTorch, and scientific computing tools**.

✅ Ability to work independently and collaboratively in an **interdisciplinary research environment**.