



## 2023 Helmholtz – OCPC – Programme for the involvement of postdocs in bilateral collaboration projects

### PART A

**Title of the project:**

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Reinforcement learning for the optimisation and control of particle accelerators

**Helmholtz Centre, division:**

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DESY-M

**Project leader:**

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Annika Eichler

**Contact Information of Project Supervisor: (Email, telephone)**

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**Web-address:**

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<https://accelerators.desy.de/> , <https://msk.desy.de/>

**DESY Group:**

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Maschine Strahlkontrollen (MSK)

**DESY-OCPC Programme Coordinator (Email, telephone and telefax)**

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**Description of the project:**

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Reinforcement learning is a subfield of machine learning that involves training an agent to take actions in an environment based on observations of the latter in order to maximize a reward signal [1]. Work from various fields has shown that reinforcement learning is capable of solving highly complex control problems. Examples include the magnetic confinement of plasma in a Tokamak reactor[2], solving a Rubik's cube using a humanoid robot hand, and tuning particle accelerators[3].

Particle accelerators are essential for scientific research across many fields, including physics, material science, and medical applications. These machines use electromagnetic fields to accelerate charged particles to extremely high energies, allowing scientists to study the fundamental properties of matter and the nature of the universe. Particle accelerators have enabled many significant scientific discoveries, such as the discovery of the Higgs boson and the development of advanced cancer therapies. However, commissioning and operating these highly complex machines presents many challenges, including the time and expertise for tuning and optimization, to achieve repeatability, and the ever growing demands on experimental requirements as well as the need for intelligent and capable control systems.

Reinforcement learning, therefore, promises to be particularly useful in the context of particle accelerators, where in operation, a large number of complex control and optimisation problems have to be solved with the goal of maximizing performance, reducing setup times and enabling autonomous operation. Some initial studies of applying reinforcement learning have successfully demonstrated that training reinforcement learning agents on accelerator control and optimisation



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tasks can yield significant improvements in both the final achieved machine state as well as the time it takes to achieve such a state [4].

The goal of this project is to apply reinforcement learning to the European XFEL at DESY in Hamburg, the world-largest free electron laser[5]. Before RL agents can be widely deployed to accelerator control rooms on a large variety of tasks, many challenges, like the high cost of samples, sparse availability of fast simulation, difficult sim2real transfer as well as machine safety, remain to be solved. To address these challenges, the postdoc should explore training in simulation including various sim2real transfer methods or studying the efficiency and safety of using model-based reinforcement learning algorithms on the real accelerators themselves.

- [1] Sutton, R. S., & Barto, A. G. (2018). Reinforcement learning: An introduction. MIT press.
- [2] Degraeve, J., Felici, F., Buchli, J., Neunert, M., Tracey, B., Carpanese, F., ... & Riedmiller, M. (2022). Magnetic control of tokamak plasmas through deep reinforcement learning. *Nature*, 602(7897), 414-419.
- [3] Eichler, A., Burkart, F., Kaiser, J., Kuroopka, W., Stein, O., Bründermann, E., ... & Xu, C. (2021, May). First steps toward an autonomous accelerator, a common project between DESY and KIT. In 12th Int. Particle Accelerator Conf.(IPAC'21), Campinas, Brazil.
- [4] Kaiser, J., Stein, O., & Eichler, A. (2022, June). Learning-based optimisation of particle accelerators under partial observability without real-world training. In International Conference on Machine Learning (pp. 10575-10585). PMLR.
- [5]"The European X-Ray Free Electron Laser Technical Design Report", <http://xfel.desy.de>

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#### **Description of existing or sought Chinese collaboration partner institute :**

Ideally, the Chinese collaboration partner institute is a world-famous machine learning or reinforcement learning research centre or an accelerator research laboratory. An institute with expertise in both or experience with applying reinforcement learning to other real-world physical systems would be an even more suitable partner.

One of the potential partners that we believe could bring their expertise in artificial intelligence to the project is ShenZhen Technology University with Prof. Bingding Huang from the college of Big Data and Internet.

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#### **Required qualification of the postdoc:**

- PhD in computer science, electrical engineering, etc.
- Experience with machine learning (reinforcement learning is welcome)
- Additional skills in programming (Python is welcome)
- Interest in working in a highly interdisciplinary environment with cutting edge real-world physical research facilities, such as particle accelerators or fusion reactors is a big advantage
- Language requirement: Fluent in English