# Studies on Using Reinforcement Learning Methods for Controlling the Transverse Beam Parameters at ARES

## First Steps Toward an Autonomous Accelerator

Oliver Stein, Annika Eichler & Jan Kaiser

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# Helmholtz AI Autonomous Accelerator Project

## A collaboration between DESY and KIT funded by Helmholtz AI fund

**Goal:**

**Automate the accelerator start-up by using intelligent process control, e.g. reinforcement learning**

- Project funded for 2 years
- Partners: DESY, KIT
- Accelerators: ARES SINBAD, FLUTE
- Bi-weekly meetings
  From DESY: Annika Eichler, Jan Kaiser, Oliver Stein, Florian Burkart, Willi Kuropka
  From KIT: Erik Bründermann, Andrea Santamaria Garcia, Chenran Xu
- Knowledge and tech exchange

**Research Topics:**

- Understand, compare, extend and apply different reinforcement learning algorithms (TD3, DDPG, PPO, ...)
- Investigate reinforcement learning methods for accelerator based application
- Apply reinforcement learning on accelerators:
  - ARES beam focusing
  - FLASH SASE tuning
- Test transferability of expertise and software between different accelerators:
  - ARES DESY
  - FLUTE KIT

# Reinforcement Learning

## Short Intro

**Reinforcement learning**

A machine learning approach where a software agent learns iteratively to act on an environment based on observations in order to solve a given task by maximising a cumulative reward.

**Notation**

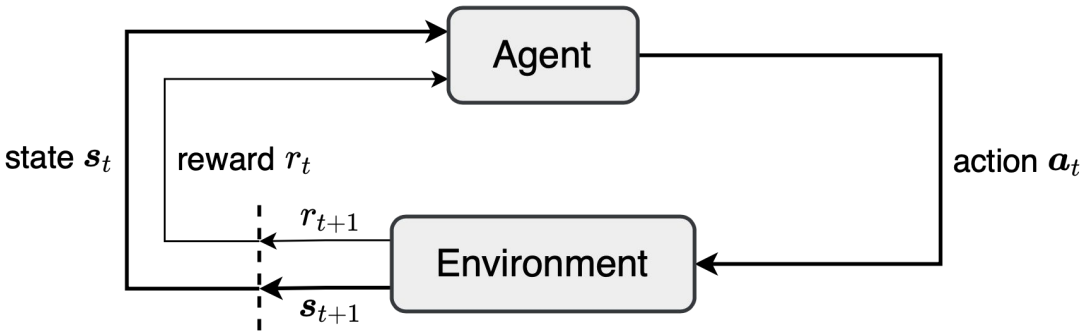
State $s_t$ (observation $o_t$)

Based on the observation of state $s_t$ the agent following the policy $\pi$ chooses an action $a_t$

$$\pi(s_t) = a_t$$

The action is applied the environment: Transitions from state $s_t \rightarrow s_{t+1}$

Reward $r_t = r(s_t, a_t)$



# Reinforcement Learning for Accelerator Optimisation

## Proof of concept at ARES

**Task**

Position and focus the electron beam on a diagnostic screen in the ARES Experimental Area

**Motivation**

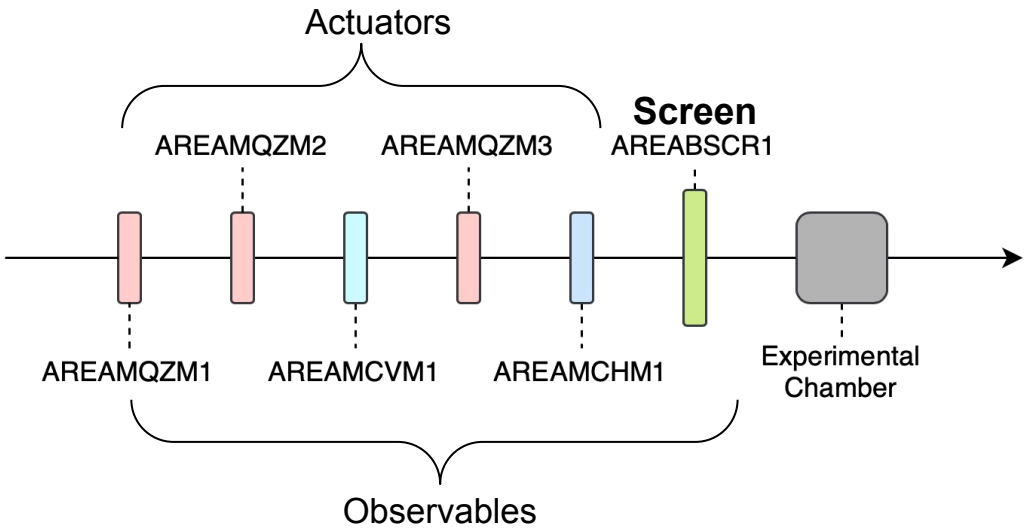
- Recurring problem from ARES operation
- Simple enough to still understand what agent does, yet complex enough to be interesting
- ARES as an easily accessible testbed to eventually map experiences to larger machines like European XFEL and FLASH

# The ARES Environment

## Proof of concept at ARES

**The environment**

- Electron beam distribution tracked through the accelerator lattice (linear beam dynamics)
- Actuators: 3 Quadrupoles, 2 Correctors
- The observables
  - From Screen:
    - Beam size (σx, σy)
    - Beam position (μx, μy)
  - Magnet settings



# Reward Signal and Beam Parameters

## Proof of concept at ARES

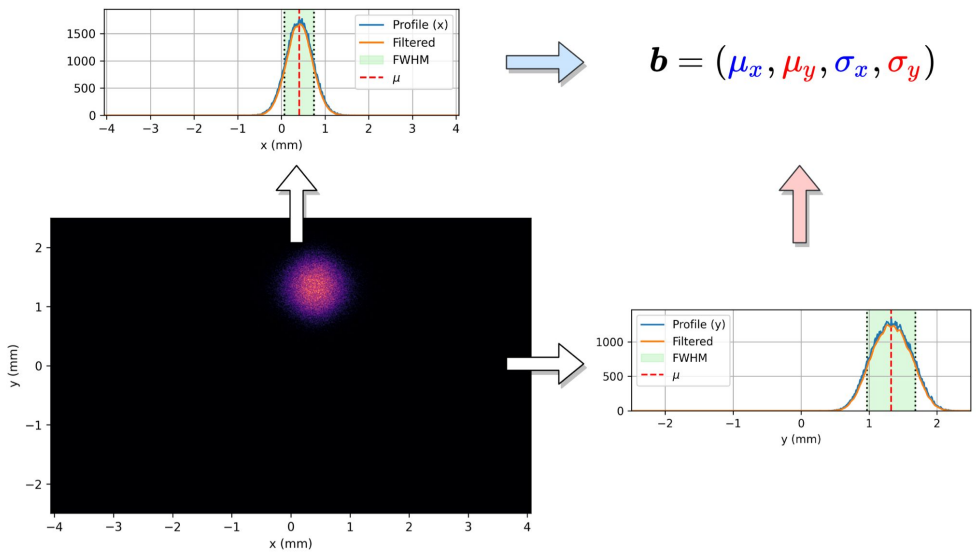
**Reward calculation**

Reward based on the improvement of the objective function from the last to the current state.
Objective function: Natural logarithm of the weighted sum of differences of
the actual beam parameters and the desired ones.

$$O(\boldsymbol{x}) = \ln \sum_{p \in \boldsymbol{b}_S, p' \in \boldsymbol{b}'_S} \alpha_p \left| p - p' \right|$$

Beam Parameters $\boldsymbol{b}_S = (\mu_x, \mu_y, \sigma_x, \sigma_y)$

Actuators $\boldsymbol{x} = (k_{Q_1}, k_{Q_2}, k_{Q_3}, \alpha_{C_v}, \alpha_{C_h})$




**Reading Beam Parameters**

1. Averaging images and applying filters for smoothing the image data
2. Beam size (σ) = FWHM / 2.355
3. Beam position (μ) = centre of the FWHM interval

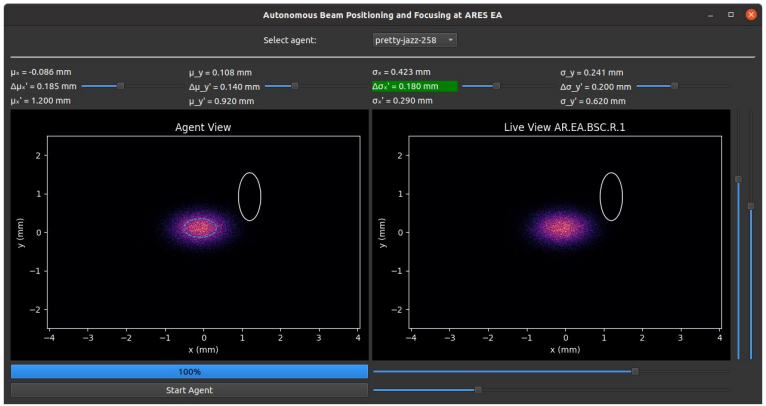
# Current status

## Proof of concept at ARES

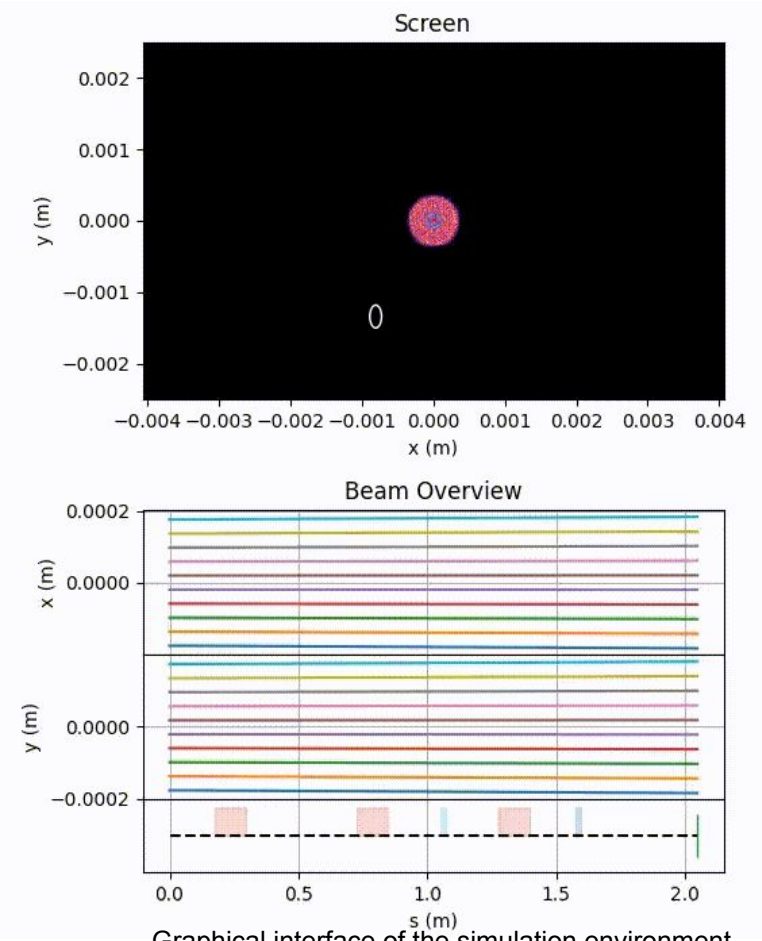
Within the training environment the trained agents can adjust the magnet settings in order to reach the desired beam parameters.

First tests indicate that the agents can adjust the beam parameters at ARES towards the goal.

Validation measurements are scheduled for the next days.




GUI, allowing the operator to set target beam parameters and to start a trained agent.




Graphical interface of the simulation environment.

# Thank you!

## Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Oliver Stein, Annika Eichler & Jan Kaiser
Machine Beam Control (MSK)
oliver.stein@desy.de | annika.eichler@desy.de | jan.kaiser@desy.de