# Al4Accelerators team activities

Andrea Santamaria Garcia 14-03-2025

### **Doctoral student graduation**

Reinforcement Learning for Autonomous Accelerators







<u>"Real-time reinforcement</u> <u>learning with online training</u> <u>for large-scale facilities"</u>

First deployment in an accelerator learning purely online and running on hardware

Reinforcement Learning for Autonomous Accelerators



### The Reinforcement Learning for Autonomous Accelerators Collaboration Workshops



Speakers: Andrea Santamaria Garcia, Annika Eichler

Christian Contreras Campana, Christian Hespe, Simon Hirländer, Jan Kaiser, Sabrina Pochaba, Borja Rodriguez Mateos, Chenran Xu

### **Reinforcement Learning**

**Reinforcement learning** is a promising learning paradigm that can open the door to **autonomous control** in accelerators

- It can learn without a model of the dynamics by purely sampling the environment.
- Deep RL can deal with continuous infinite environments thanks to function approximation.
- Fastest convergence speed in optimisation problems.
- Deals with non-stationary environments and delayed consequences.

**Real-world deployment challenges**: partial observability, sample efficiency, safety, robustness, and generalisation.

Reinforcement Learning for Autonomous Accelerators





RL remains relatively unknown in the accelerators community

→ Considerable upfront engineering investment (algorithm design, tuning, and training, deployment)

### The RL4AA mission

- **Connect** RL enthusiasts within the particle accelerator community to foster collaborative projects across institutions and facilitates interaction with other RL experts for the exchange of ideas.
- Educate on both fundamental and advanced RL concepts and demonstrate practical applications in accelerators, offering valuable resources such as programming tutorials, lectures, and educational events.
- **Facilitate discussions** on the challenges of developing and deploying RL algorithms in particle accelerators and other large-scale infrastructures.
- **Streamline and speed up** the research process to uncover foundational, domain-specific solutions.

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Github: https://github.com/RL4AA Discord: https://discord.gg/rudtJaeW Website: https://rl4aa.github.io/ Youtube channel: https://www.youtube.com/@RL4AAColl aboration Paper: DOI:10.18429/JACOW-IPAC2024-TUPS62



### RL4AA'23 in Karlsruhe

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https://indico.scc.kit.edu/event/3280/

- 2 days
- 35 participants
- RL introductory lectures
- <u>Coding tutorial</u>
- Meet and greet talks
- Seminar
- Discussion groups and advanced discussion session
- Accelerator facility tour
- Social events

### **RL4AA'24 in Salzburg**



https://indico.scc.kit.edu/event/3746/

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- 3 days
- 56 participants
- RL crash course
- <u>Advanced coding tutorial</u> with lecture
- Two keynote speakers
- Facility talks
- Invited talks
- Student talks
- Poster session
- Closing discussions
- Social events

### **Keynote speakers 2024**

Reinforcement Learning for Autonomous Accelerators



Antonin Raffin Maintainer of Stable Baselines 3 and research engineer German Aerospace Center (DLR)



### <u>Designing and Running</u> <u>Real-World RL Experiments</u>

YouTube video

### **Keynote speakers 2024**

Reinforcement Learning for Autonomous Accelerators



FelixLead research scientistBerkenkampBosch Center for Al



### **Towards real-world RL**

YouTube video

### **Tutorial 2024**

#### Meta Reinforcement Learning for steering tasks

#### Use case: AWAKE beamline at CERN

#### Implementation example for the RL4AA'24 workshop

Simon Hirlaender, Jan Kaiser, Chenran Xu, Andrea Santamaria Garcia

#### The accelerator problem we want to solve

The goal is to **minimize** the distance  $\Delta x_i$  of an **initial beam trajectory** to a **target trajectory** at different points *i* across the accelerator(here marked as "position") in the least amount of steps.



#### https://github.com/RL4AA/rl4aa24-tutorial

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### RL4AA'25 in Hamburg







#### https://indico.scc.kit.edu/event/4216/

- 3 days
- 73 participants
- RL introductory lecture
- Coding challenge with prizes
- Keynote speakers
- Talks
- Poster session
- Accelerator facility tour
- Social events

### Looking at the numbers

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### **Keynote speakers 2025**

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Jan Peters

**Professor for Intelligent Autonomous Systems** TU Darmstadt



### Inductive Biases for Robot Reinforcement Learning

### **Keynote speakers 2025**

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#### Alessandro Swiss Plasma Center Pau EPFL



Plasma integrated control and trajectory optimization via reinforcement learning: applications in magnetic confinement fusion

#### Reinforcement Learning for Autonomous Accelerators



#### **ARES (Accelerator Research Experiment at SINBAD)**

ARES is an S-band radio frequency linac at the DESY Hamburg site equipped with a photoinjector and two independently driven traveling wave accelerating structures. The main research focus is the generation and characterization of sub-femtosecond electron bunches at relativistic particle energy. The generation of short electron bunches is of high interest for radiation generation, i.e. by free electron lasers.



- Final energy: 100-155 MeV
- Bunch charge: 0.01-200 pC
- Bunch length: 30 fs 1 ps
- Pulse repetition rate: 1-50 Hz!

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#### The accelerator problem we want to solve

We would like to focus and center the electron beam on a diagnostic screen using corrector and quadrupole magnets





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#### Reinforcement Learning for Autonomous Accelerators



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2	Reinforced Confusion	9 9 9	0.04908
3	Beam Kickers	9 9 9	0.06213
4	All good things come in 3s		0.07769
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### **Introductory lecture**





#### Slides available





### Facility tours at DESY

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### Social events

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We will be happy to welcome you in Liverpool in for RL4AA'26!

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### **MaLAPA at CERN**

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**5th ICFA Beam Dynamics Mini-Workshop** on Machine Learning for **Particle Accelerators** 

### **MaLAPA at CERN**







## Highlights from RL4AA'25

https://indico.cern.ch/event/1382428/c ontributions/6272819/



### **MaLAPA at CERN**

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### **Cheetah tutorial**

#### https://indico.cern.ch/event/13 82428/contributions/6272814/



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- Was asked to partner RL4AA with MaLAPA
- Currently date conflict with RL4AA and MaLAPA 2026
- We started and are managing the MaLAPA Discord server and website
- Will start gathering resources for the ML in accelerators community

### **Future**

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### Talks

- Invited talk at <u>IPAC'25</u> (Taiwan, 1-6 June)
- Invited talk at EuCAIF (Sardinia, 16-20 June)
- Invited talk at Particle Accelerators and Beams (Oxford, 9-10 July)

### Papers

- PRL on control of microbunching instability with RL
- RL4AA proceedings
- PRAB on online control in accelerators with RL on hardware
- NatPhys ML in accelerators review paper
- RL review paper



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### Research

- Develop wakefield capabilities in Cheetah (SLAC+CI collab)
- Integrate CLARA in Cheetah and try optimisations

### Students

• Two CERN students interested in doctoral thesis CERN+UoL