First steps toward an autonomous accelerator: a common project between DESY and KIT

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What is Autonomy?

Definition

Autonomous System:
System that can change its behaviour in response to unanticipated events during operation.

www.desy.de

	Autonomous Plant	Control Room Operation	Field Operation / Maintenance	Planning and Scheduling
0	No Autonomy: Humans carry out all necessary operations without assistance.	Humans carry out control of all assets without assistance. Low-level automation might be available (e.g., safety system).	All field operator tasks executed by humans.	Manual development of plans and the corresponding schedule.
1	Operations Assistance: Automation system provides decision support for necessary operations by remote / digital assistance. Humans always responsible.	Automation of control loops during steady-state. Manual startup and shutdown of the plant. Manual execution of transitions. Alarm based notification.	Automation system notifies humans about field activities. Some tasks are automated, e.g. operating valves.	ERP plan creation on human request. Human decides when and how to execute the plans and adapts plans.
2	Automation system is in control in certain situations on request (humans pull support, e.g. for plant startup). Humans always responsible.	Automation system assisted plant startup, transition, steady-state, and shutdown. Manual fault correction supported by decision support system.	System guided field operation tasks. Humans get instructions what to do and when by decision support system.	Adaptations of plans to current situations by operator request.
3	Automation system is in control in certain situations. Plant actively alerts to issues and proposes solutions. Humans confirm.	Automated plant shutdown, startup and transition, on human request. Automatic correction of known deviations. Decision support for unexpected/unknown faults.	Most tasks required for standard operations are automated, like shutdown, startup and transition phases. Number of humans in the field heavily reduced.	Continuous feedback and re-planning in case of production deviations. Manual schedule release.
4	Autonomous operations in certain situations: automation system has full control in these situations, humans supervise actions.	Autonomous control in certain situations with automatic fault and deviation correction and avoidance.	Almost human free field operation. Only human field operation in exceptional situations.	Continuous autonomous planning and scheduling without user interaction. Detection of production deviations and re-planning. Manual schedule release.
5	Fully autonomous operation in all situations. Humans may be completely absent.	Full autonomous control, fault correction and avoidance in all situations. No human supervision required.	Full autonomous field operation, no manual actions in the field necessary. No humans remain in the plant.	Autonomous development and execution of plans and schedules. Autonomous re-planning in case of production deviations. No human interaction.

T. Gamer et. al., “The autonomous industrial plant -future ofprocess engineering, operations and maintenance,” 12th IFAC Symposium DYCOPS, vol. 52, no. 1, pp. 454–460, 2019.

Autonomous Accelerator

Why?

- Assist researchers in repetitive or dangerous work
- Increase availability:
  - reducing time for start-up, tuning and down-time
  - Prevent down-time and reduce failures

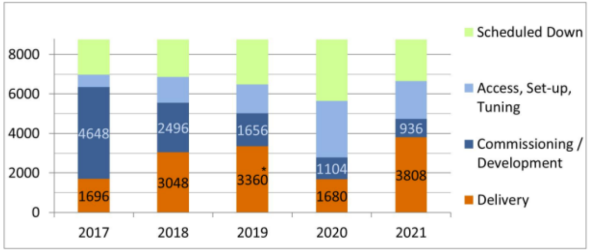

Figure: W. Decking, XFEL availability

- Push the limits of operability of the facilities:
  - Performance
  - Flexibility
  - Availability
- Allow operation also in critical situations (like in the current pandemic)

What are the challenges?

Particle accelerators:

- Largely distributed
- Various types of systems
- Strongly coupled subsystems
- Highly nonlinear processes
- High dimensionality
- High data intensity
- Hardly any long-term data available
- Heterogeneous signals
- Limited access to key observables

Levels of Autonomy

What is the current status?

Examples

- Automatic control of pumps, valves, power supplies, RF
- Safety system for infrastructure (water, power supplies, etc.)

- Drift compensation in steady state operation
- Alarm system for infrastructure (water, power supplies, etc.)

- Optimization procedures
- Automatic fault handling of known faults (state machine)

Level depends on the kind of facility (research/user facility), different for different components

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0	Humans carry out control of all assets without assistance. Low-level automation might be available (e.g., safety system).
1	Automation of control loops during steady -state. Manual startup and shutdown of the plant. Manual execution of transitions. Alarm based notification.
2	Automation system assisted plant startup, transition, steady-state, and shutdown. Manual fault correction supported by decision support system.
3	Automated plant shutdown, startup and transition, on human request. Automatic correction of known deviations. Decision support for unexpected/unknown faults.
4	Autonomous control in certain situations with automatic fault and deviation correction and avoidance.
5	Full autonomous control, fault correction and avoidance in all situations. No human supervision required.

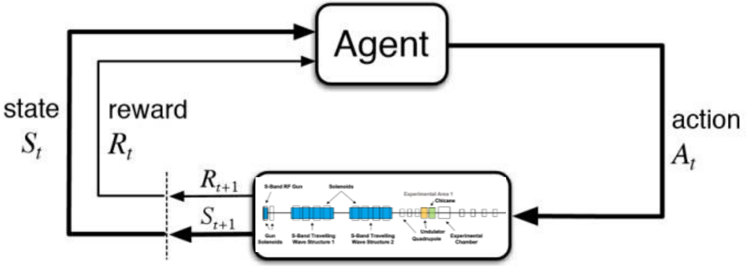
Current status

Future goal

Project Idea

Exploit artificial intelligence as an enabler for autonomy

- Apply reinforcement learning (RL) to accelerator operation (have shown capability in different work [1-7])
- RL: machine learning algorithm
  - Agent interacts with environment
  - Receives reward
  - Observes the state
  - Takes action
  - → Plan ahead

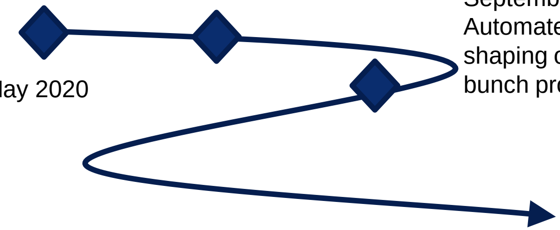


Sutton: Reinforcement Learning, an introduction

- Transferability
  - Possible with two similar research facilities in the project
  - How much facility-specific adaption will be necessary?
  - Enabled by standardized interfaces and simulation environments

Helmholtz AI project details

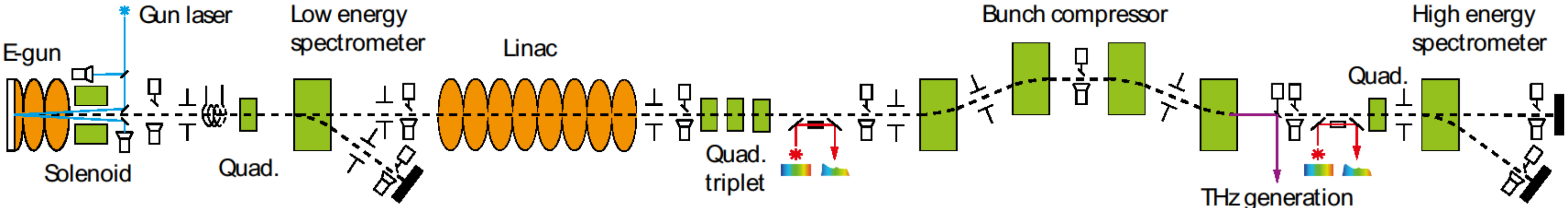
- Collaboration between KIT & DESY
- 2 years
- Research facilities:
  - ARES (DESY)
  - FLUTE (KIT)



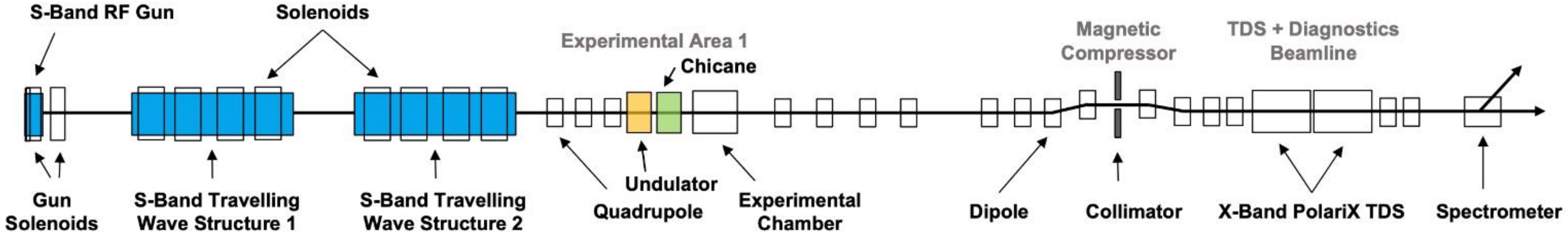
Facilities

	FLUTE	ARES
Final electron energy [Me]	40-50	100-155
Electron bunch charge [pC]	1-3000	0.5-30
Electron bunch length [fs]	1-300	0.2-10
Pulse repetition rate [Hz]	1-10	10-50

FLUTE [M. Nasse, et. al., "First electron beam at the linear accelerator FLUTE at KIT," in IPAC 2019, 2019]



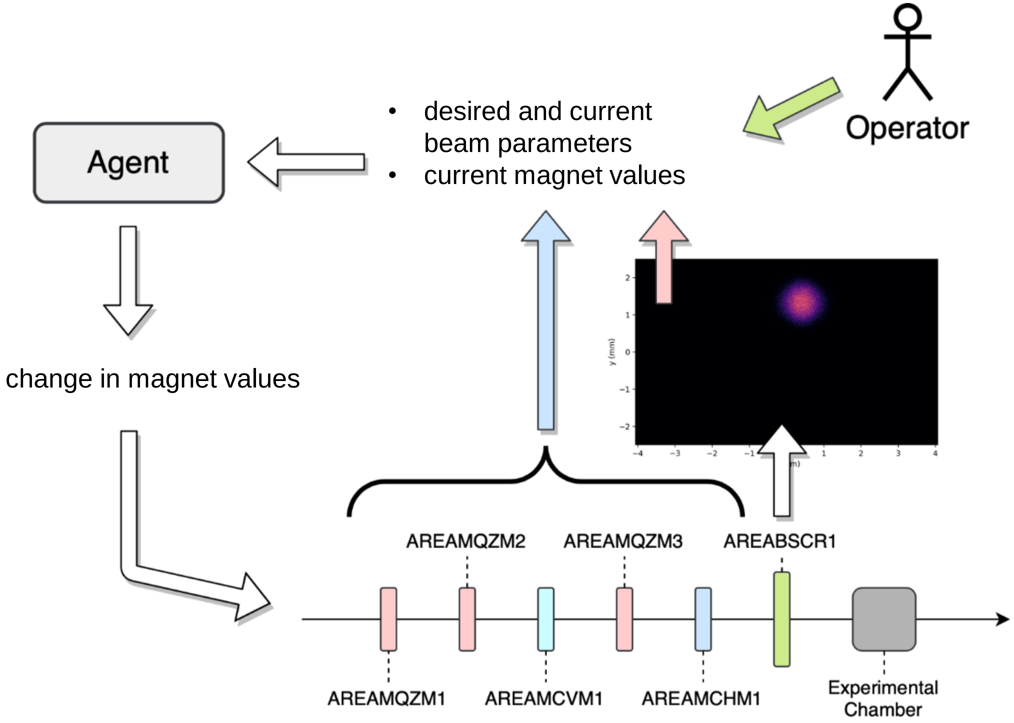
ARES [E. Panofski, et. al., "Status Report of the SINBAD-ARES RF Photoinjector and LINAC Commissioning," in IPAC, 2019]



Beam Focusing

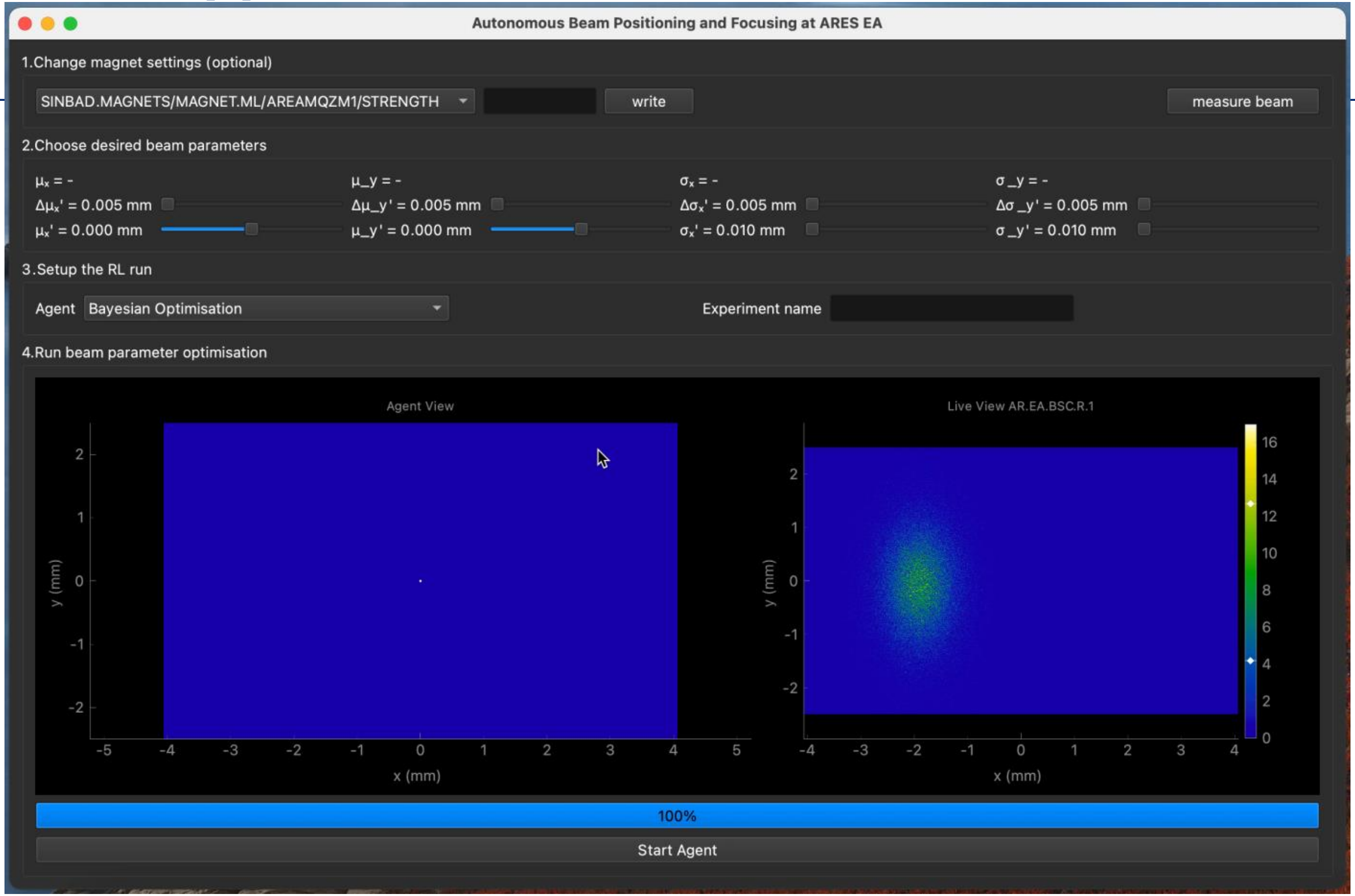
First proof of concept

- Task
  - Position and focus the electron beam on a diagnostic screen in the ARES Experimental Area
- Motivation
  - Recurring problem from ARES operation.
  - Similar setup at FLUTE
  - Simple enough to still understand what agent does, yet complex enough to be interesting.



Control Room Application

Prototype



Thanks for listening!

Thanks to the whole project team!