



Contribution ID: 21

Type: **Poster**

Towards Few-Shot Reinforcement Learning in Particle Accelerator Control

This paper investigates the automation of particle accelerator control using few-shot reinforcement learning (RL), a promising approach to rapidly adapt control strategies with minimal training data. With the advent of advanced diagnostic tools and increasingly complex accelerator schedules, ensuring reliable performance has become critical. We focus on the physics simulation of the AWAKE electron line—a representative platform that allows us to disentangle the intrinsic control challenges from the performance of various algorithmic approaches.

In our study, we address two primary challenges: the scarcity of high-fidelity simulations and the presence of partially observable environments. To overcome these hurdles, we apply well-established methods in a novel context. Specifically, we leverage meta-reinforcement learning to pre-train agents on simulated environments with variable uncertainties, enabling them to quickly adapt to real-world scenarios with only a few additional training episodes. Moreover, when suitable simulations are unavailable or prohibitively costly, we employ a model-based strategy using Gaussian processes to facilitate efficient few-shot direct training.

While the underlying methods are not new, their application in the particle accelerator domain represents a significant step forward. Our results demonstrate that few-shot RL can markedly enhance control efficiency and adaptability, paving the way for more robust and automated accelerator operations. This work thus opens new avenues for integrating advanced RL techniques into complex physical systems, bridging the gap between simulation and real-world deployment.

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Session Classification: Poster session