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Bayesian Optimization and Real-Time Control in the Muon EDM Experiment at PSI

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Designing high-precision particle physics experiments involves optimizing over complex, computationally expensive simulations, often under significant uncertainty—particularly in inputs such as magnetic field maps. In the Muon EDM experiment at PSI –which aims to measure the Electric Dipole Moment (EDM) of the muon using the frozen spin technique –the injection of muons into the experiment is very sensitive, requiring expensive simulations to be optimized.

We apply Bayesian optimization with Gaussian processes to efficiently optimize the experimental parameters to maximize injection efficiency. This approach enables sample-efficient optimization, quantifies uncertainty, and provides tolerance estimates for the experimental parameters. However, due to potential deviations in the magnetic field, a purely feed-forward design strategy is insufficient. To bridge this sim-to-real gap, we are developing real-time feedback control strategies that adaptively tune operational parameters—such as coil currents and injection timing—during runtime.

This hybrid approach enables optimization of the experimental geometry offline, while robustly compensating for real-time fluctuations, improving the reliability and performance of the experiment.

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