Karlsruher Institut für Technologie

RF2.0 RESEARCH FACILITY
TOWARDS A MORE ENERGY-EFFICIENT AND SUSTAINABLE PATH

IPAC25 THPM018

Efficient accelerator operation with artificial intelligence based optimization methods

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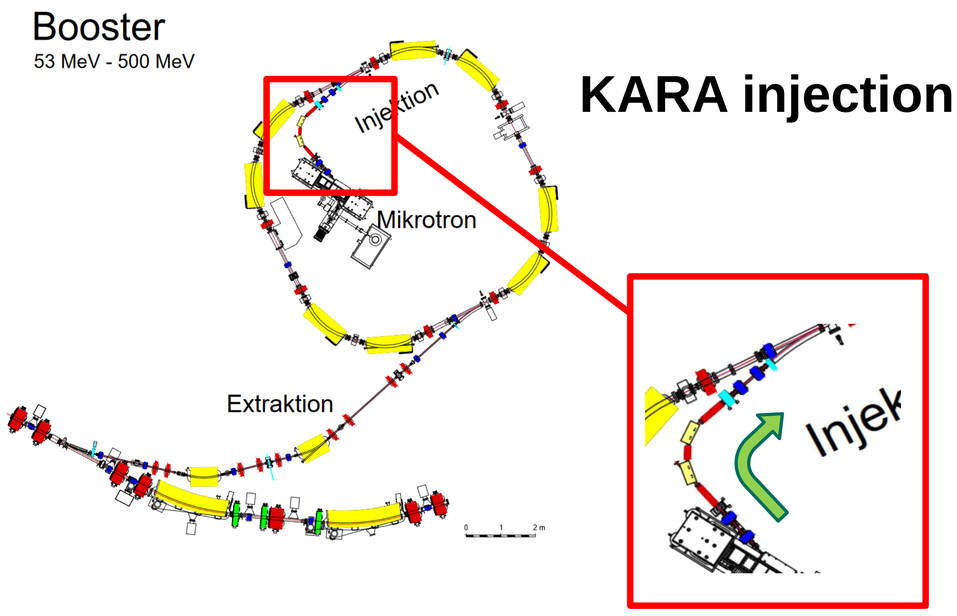
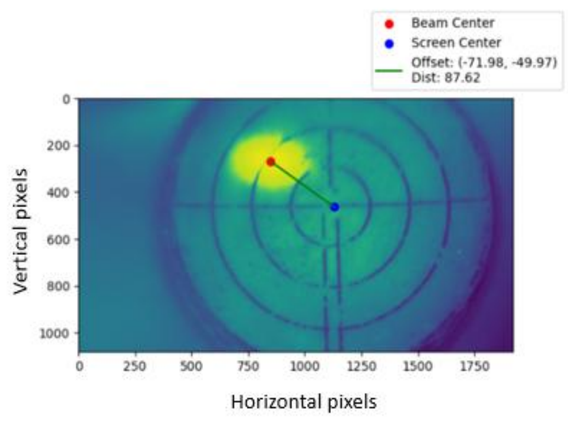
Introduction





- Deflection of the particle beam
- Increased energy loss
- Reduced beam efficiency and performance
- Errors in diagnostics

Bayesian Optimization (BO) / BAX / Cheetah code

Beam Alignment using BAX

Quadrupole magnet tuning is not just a black-box optimization problem. It involves physics, constraints, safety, and a rich structure in parameter space. BAX gives flexibility to reason analytically and structurally about decisions. Let $\mathbf{x} = [s_1, s_2, \ldots, s_k, q]$ represent the upstream steering magnet settings s_i and the quadrupole strength q. A GP is used to model the beam centroid position $y(\mathbf{x})$ on a downstream screen [6].

Using a degree-1 polynomial product kernel:

$$k(\mathbf{x}, \mathbf{x}') = \prod_{i=1}^{k+1} (1 + x_i x_i'),$$

we ensure that the surrogate model reflects the approximately linear and independent influence of each magnet.

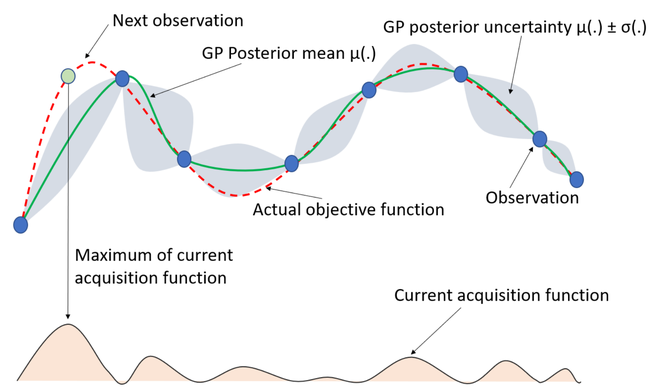
To compute beam deflection for fixed steering settings $\mathbf{s}$, the slope with respect to q is evaluated as:

$$\Delta y = \frac{y([\mathbf{s}, q_2]) - y([\mathbf{s}, q_1])}{q_2 - q_1}.$$

Here, q_1 and q_2 represent two slightly different strengths the same quadrupole magnet, used to evaluate the beam's sitivity to quadrupole variations. By measuring the downeam beam position y at both strengths, we approximate the rivative of the beam position with respect to quadrupole ength. The alignment objective becomes:

$$\mathbf{s}^* = \arg\min_{\mathbf{s}} \left| \frac{y([\mathbf{s}, q_2]) - y([\mathbf{s}, q_1])}{q_2 - q_1} \right|.$$

Bayesian Optimization (BO)

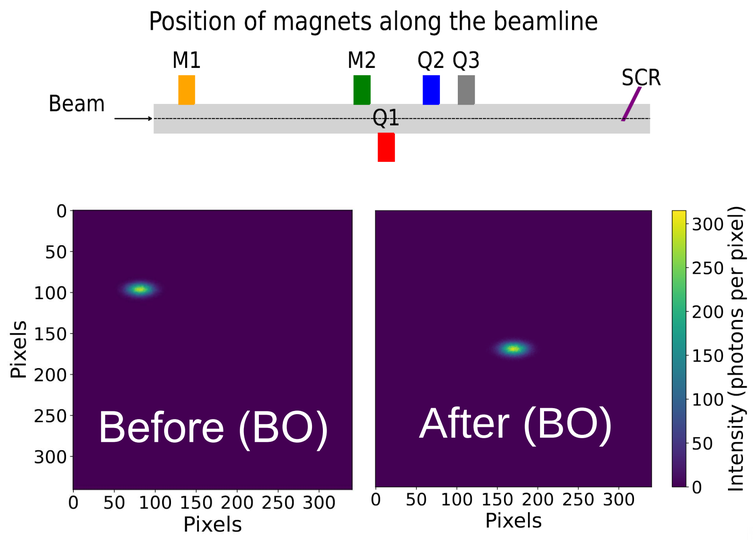


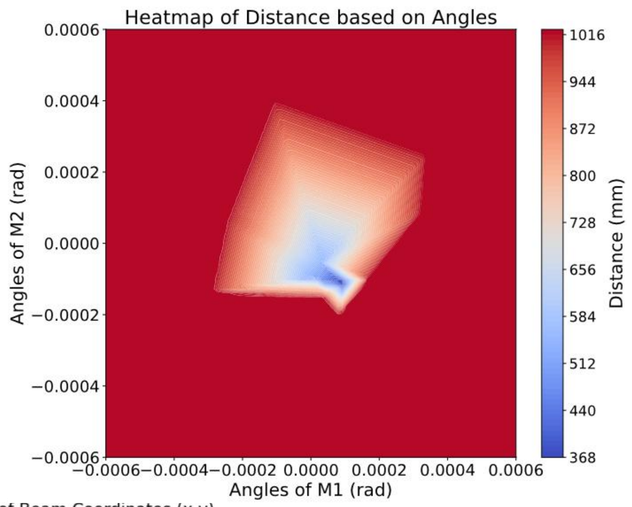
Cheetah

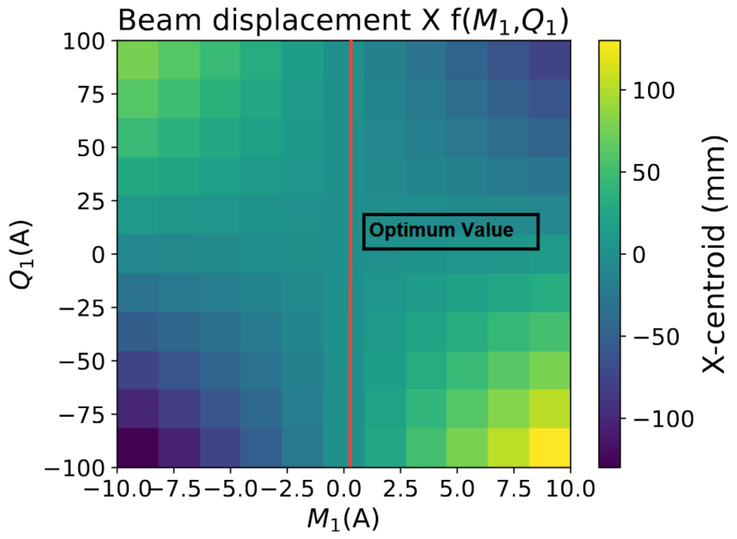
- Fast and easy-to-use differentiable simulation code for particle accelerators, developed by **DESY** and **KIT**
- Ease and speed-up the development and deployment of machine learning methods to particle accelerators

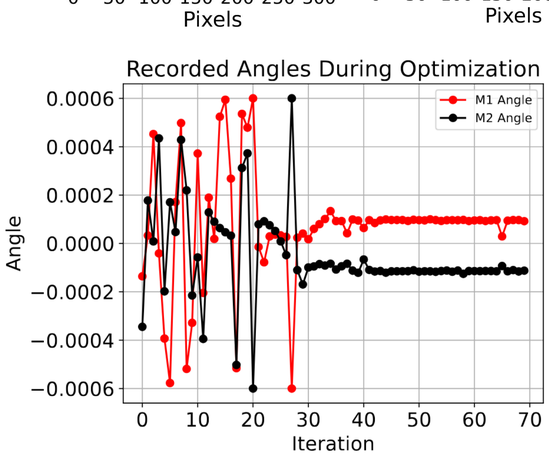
Simulations / Results

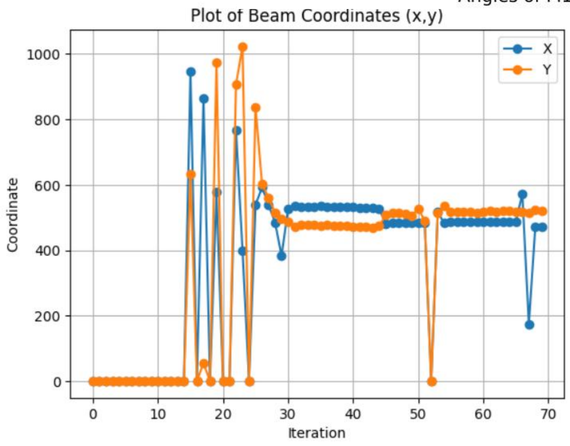
BO controlling steering magnets (M1, M2)

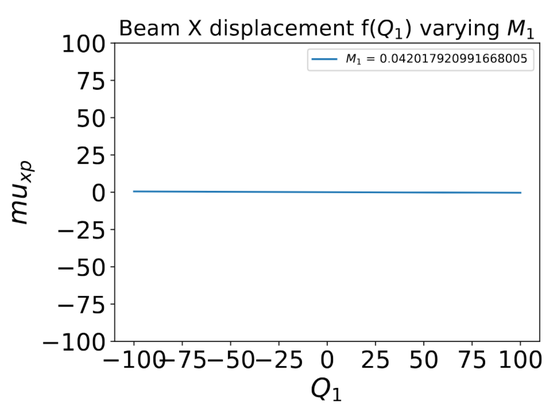


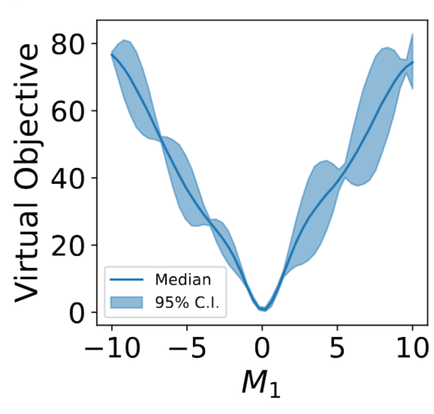












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