Automated Beam Alignment & Stabilization For Light Sources

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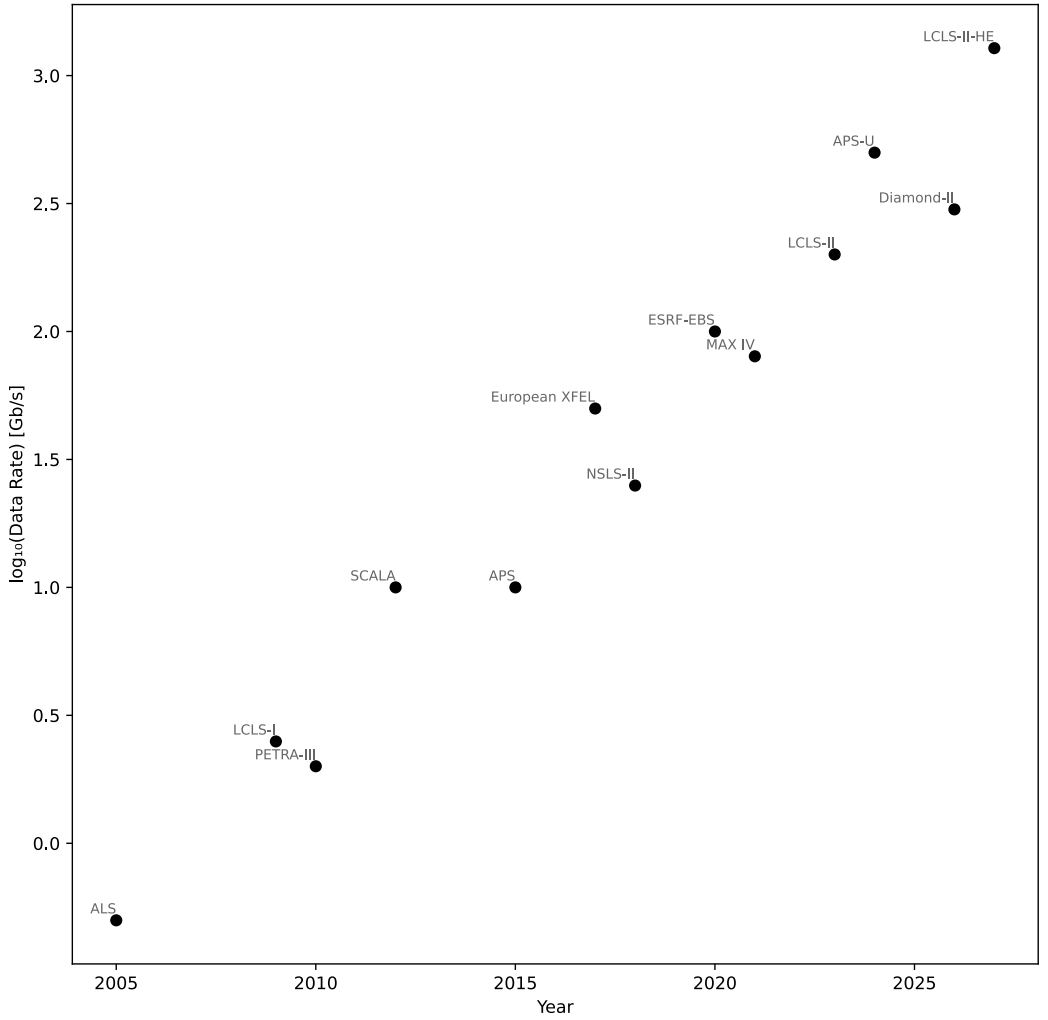
Data Generation Versus Scientific Analysis

- Widening gap between rate of data generation and rate of scientific analyses.
- Upgrades to APS, LCLS-II-HE -> more ambitious experiments.
- Increasingly stringent requirements for alignment and control.



A Start to End Approach towards Data & Modeling

- Different stages in experiments: injector to detector on to post-experimental analyses.
- Different software, codes, versions; protocols; error tolerances, etc ➢ Tower Of Babel.
- Need a Start To End framework for Modeling, Control & Data processing.

A Start to End Approach towards Data & Modeling

- Uniform Platforms: APIs, updates & debugging, model compatibility.
  Examples – Xopt, Badger, Lume, etc developed & maintained at SLAC.

- Sharing best practices, protocols and exemplars.
  Similar fields can have *similar* problems that may yield to *similar* algorithms.

- Constitution of teams, etc.
  Domain experts, hardware and software engineers, etc.

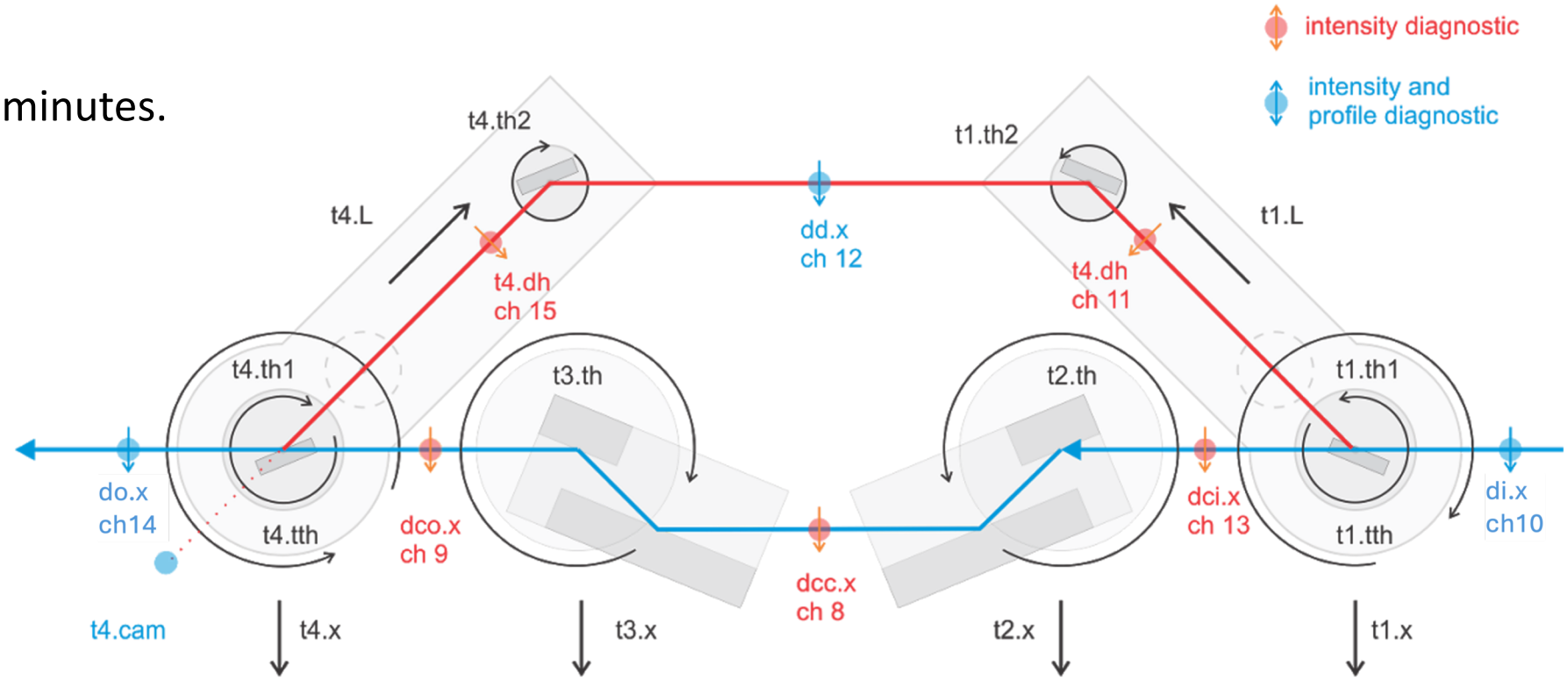
Xopt: Optimization for arbitrary problems.

- Python package for flexible optimization of arbitrary problems.

- Goal: Provide advanced algorithmic support for arbitrary optimization problems (simulations/control systems) with minimal required coding, with support for *multi-threaded* or *MPI*-enabled execution.

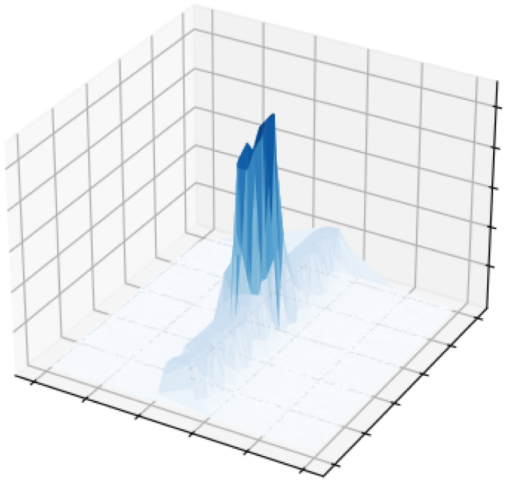
Split And Delay (SnD)

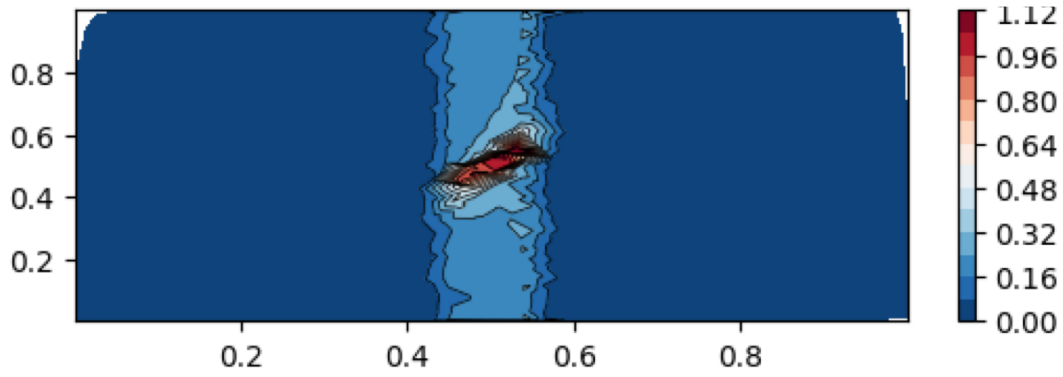
- Importance of the SnD system.
- Current set-up ~4 hours.
- Current stabilization ~ 10-15 minutes.



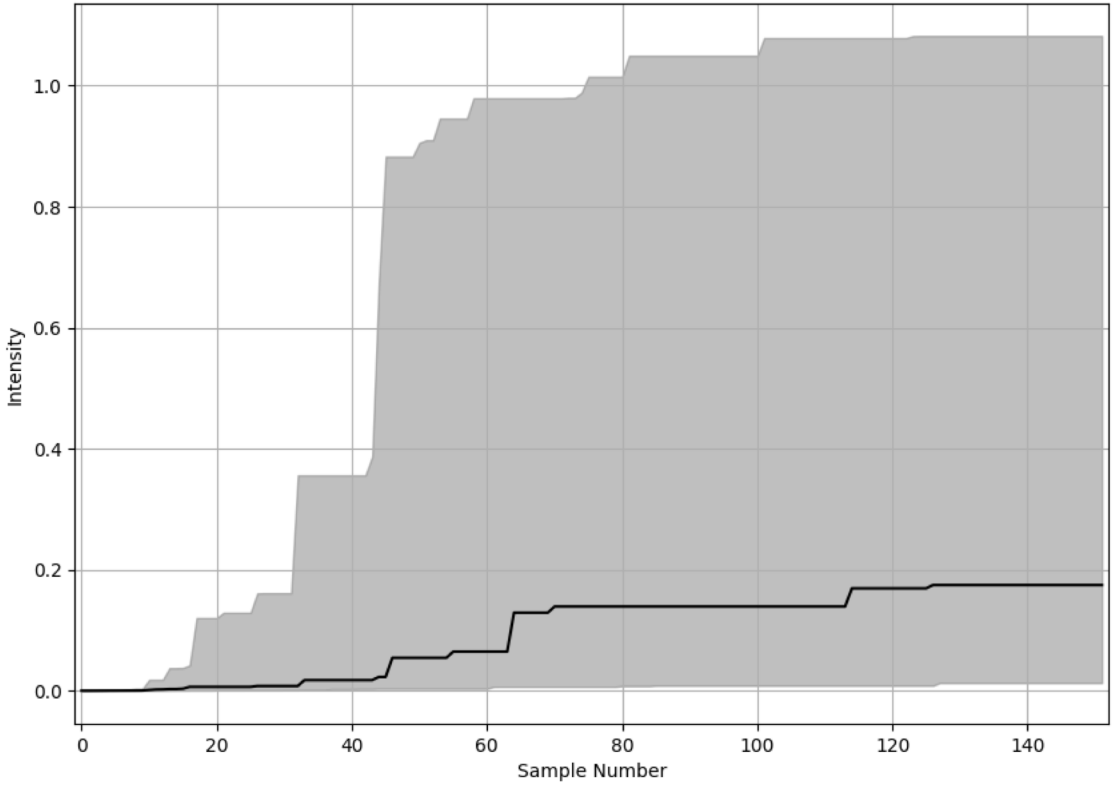
Physics Informed Bayesian Optimization

- SnD Optimization: Needle in a haystack problem.
- Learning active sub-spaces in inputs.
- Reverse annealing to control exploration-exploitation.

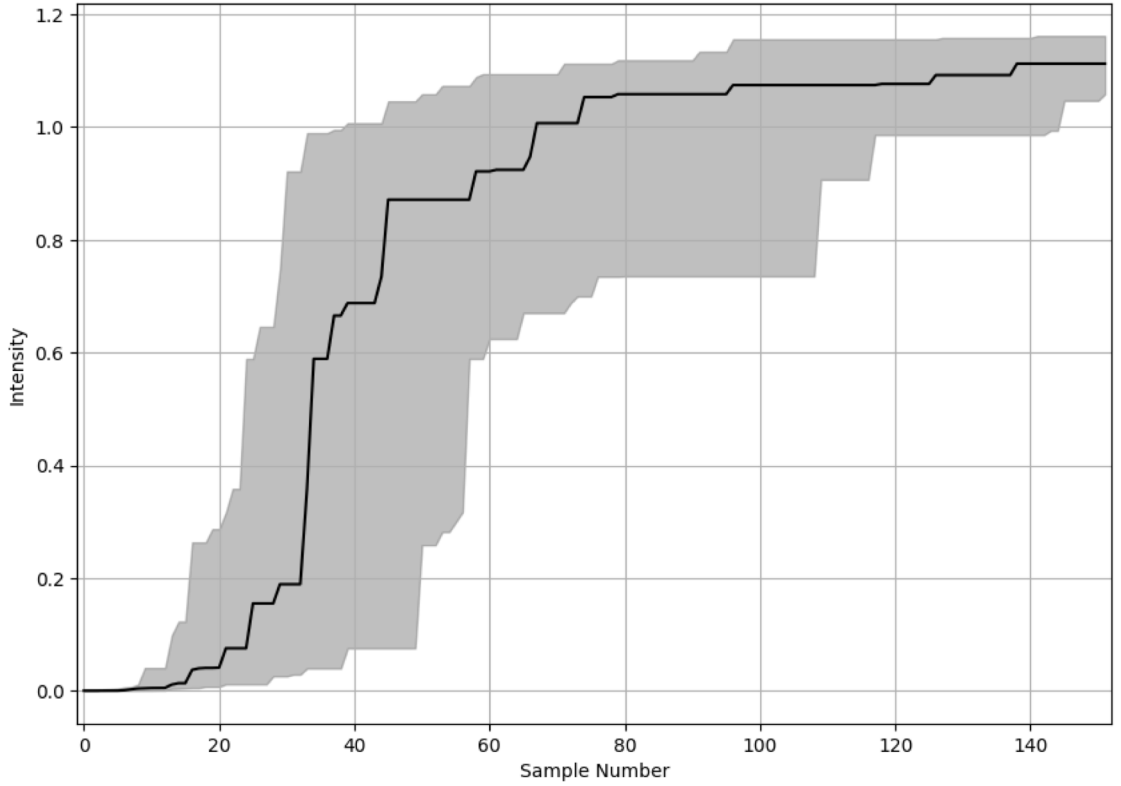




Alignment: Beam Intensity Results



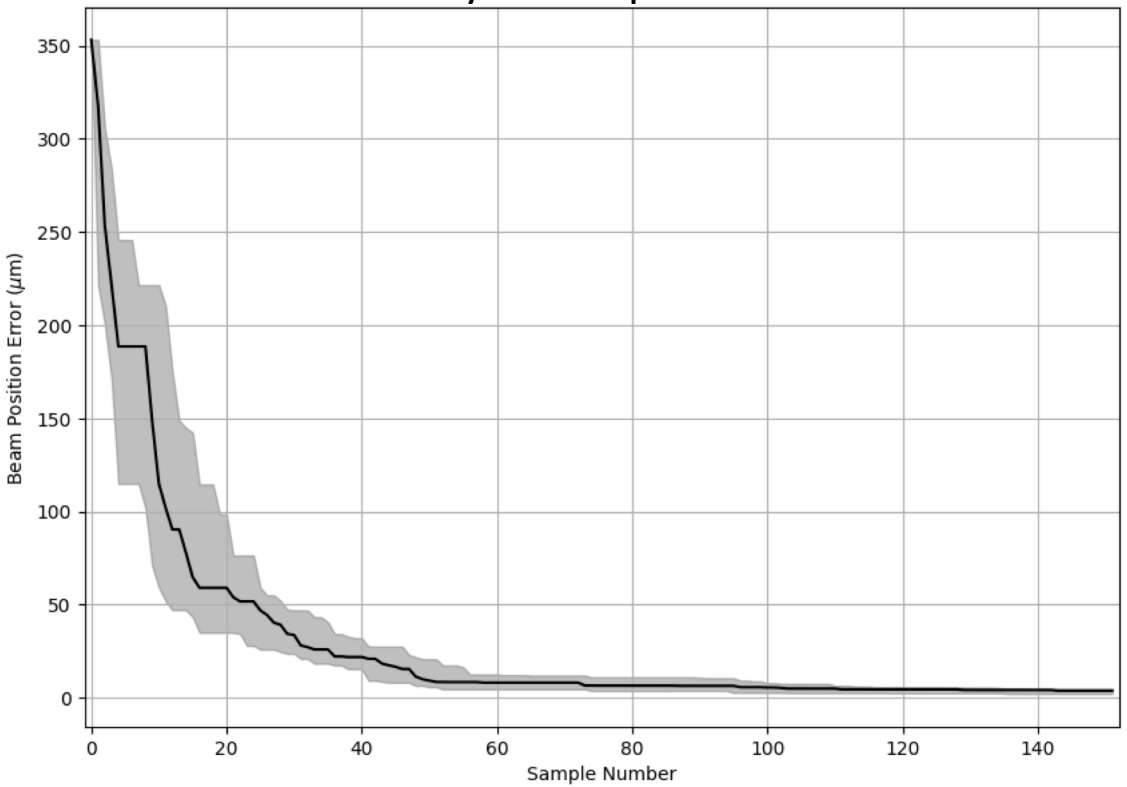
Classical Bayesian Optimization

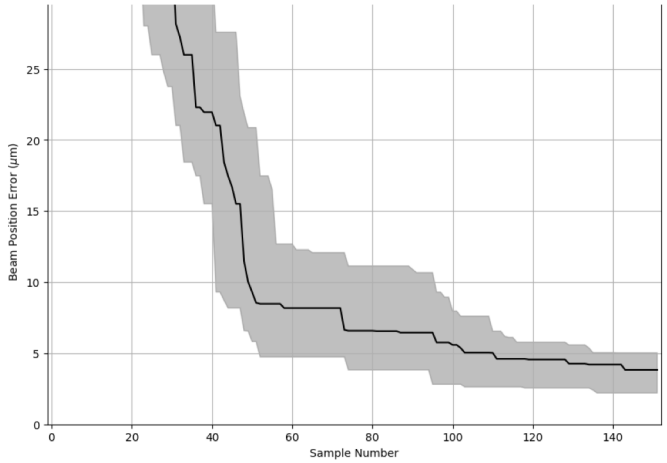


Domain Informed Bayesian Optimization

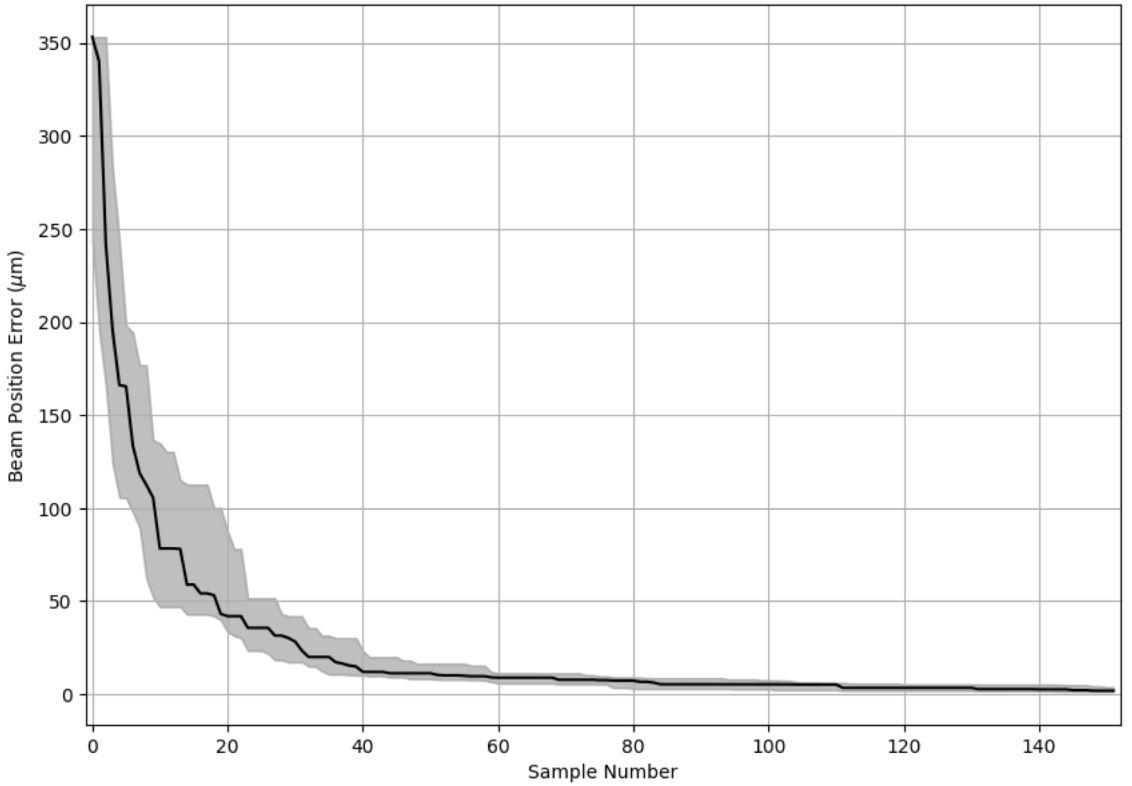
Alignment: Beam Position Error Results

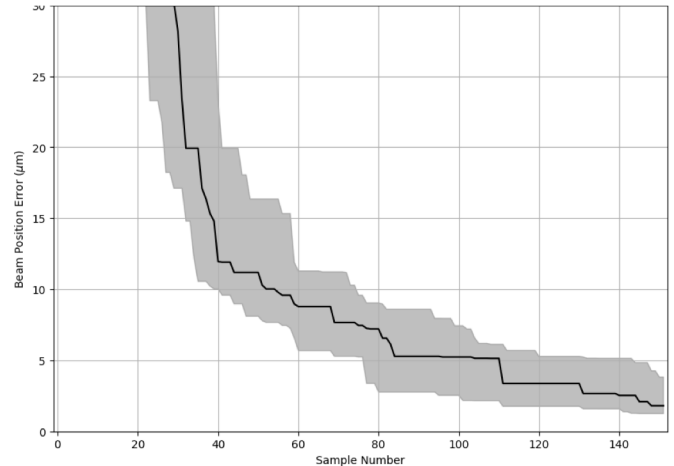
Classical Bayesian Optimization





Domain Informed Bayesian Optimization





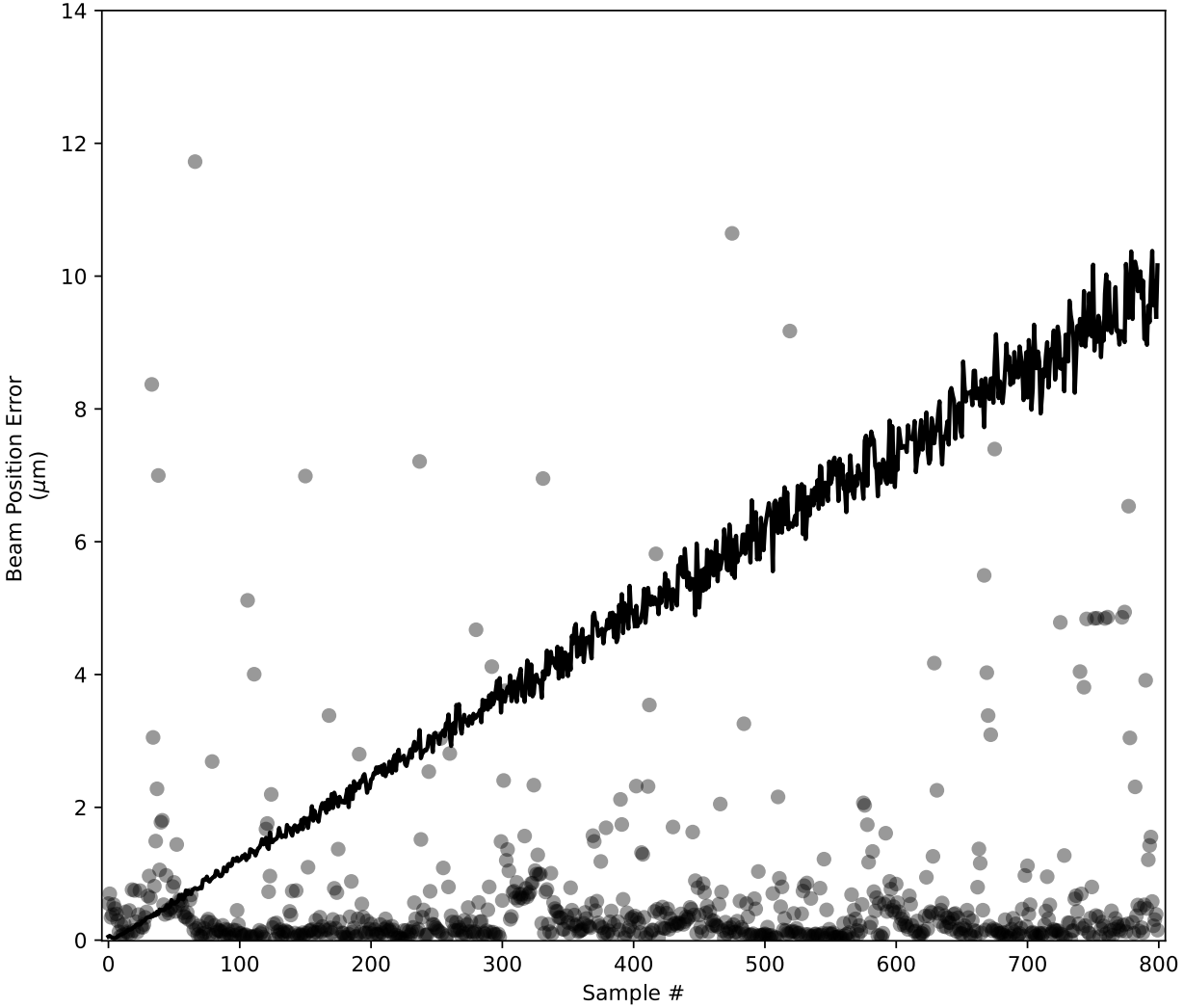
Stabilization: Drift Correction

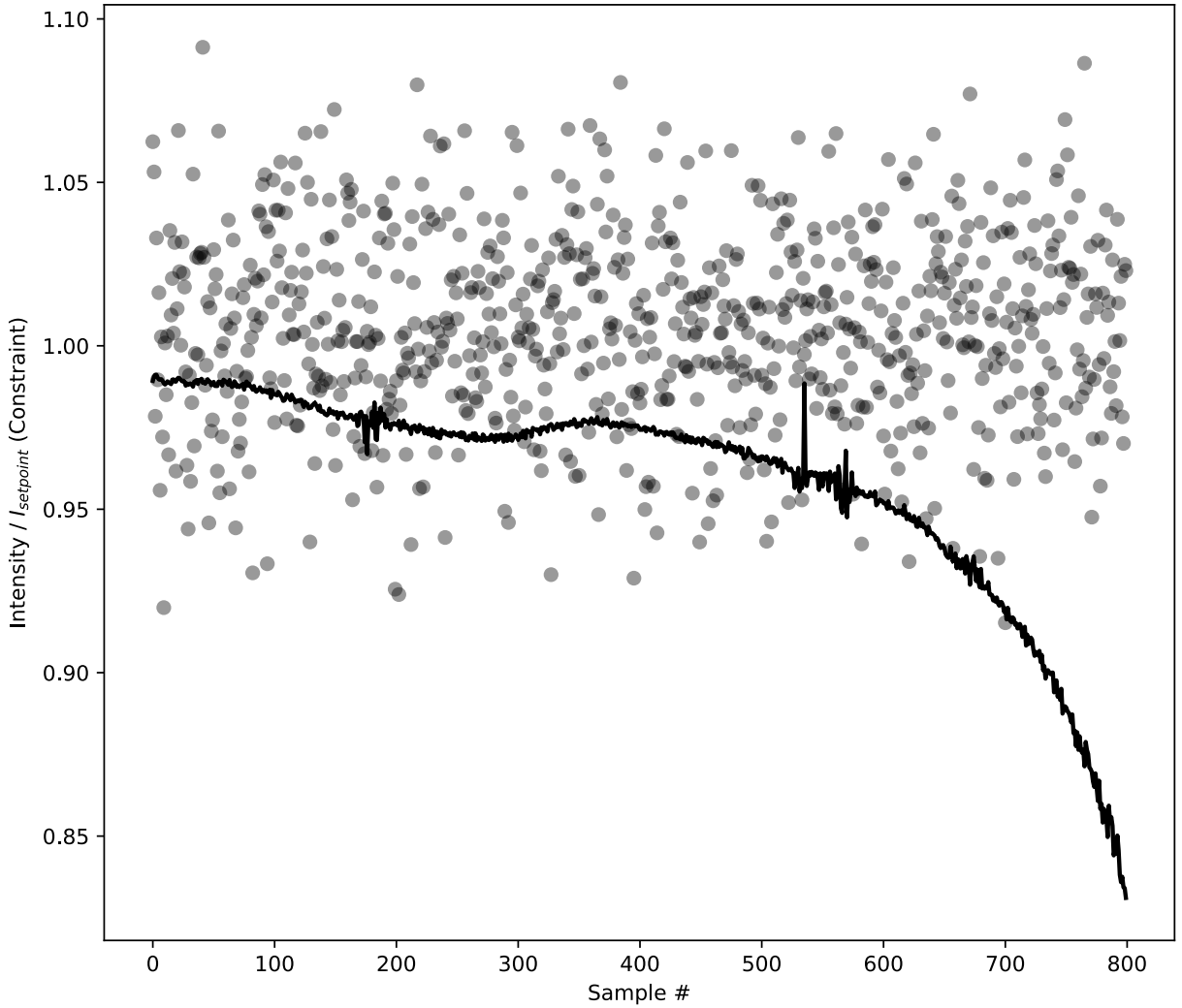
- Optimization: *get to* the optimum in ~minutes.
  Drift correction: *maintain* the optimum for ~hours.

- Current state: ~10 minutes of unimpeded operation.

- Approach: Time Varying Bayesian Optimization.

Stabilization: Time Varying Bayesian Optimization





Summary & Conclusions

- Widening gap between data generation and scientific analyses at light sources.
- Start to end framework for modeling and control at SLAC.
- Tools such as Xopt have SOTA algorithms integrated for optimization with minimal coding.

[1] Mishra, A., M. Seaberg, R. Roussel, F. Poitevin, J. Thayer, D. Ratner, A. Edelen, A. Mehta. "A Start to End Machine Learning Approach to Maximize Scientific Throughput from the LCLS-II-HE." *Synchrotron Radiation News* (2025).
[2] Mishra, A., Seaberg, M., Roussel, R., Edelen, A., Ratner, D. and Mehta, A., “Data Driven Drift Correction For Complex Optical Systems”. *Optics Express (under review), (2025)*.
[3] Mishra, A., Seaberg, M., Roussel, R., Edelen, A., Ratner, D. and Mehta, A., “Physics Informed Bayesian Optimization For Complex Systems”, *Nature Communications (under review), (2025)*.