
# AI/ML for Heavy-ion Accelerators

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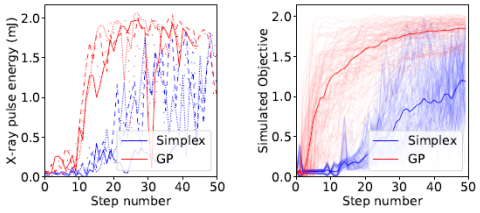
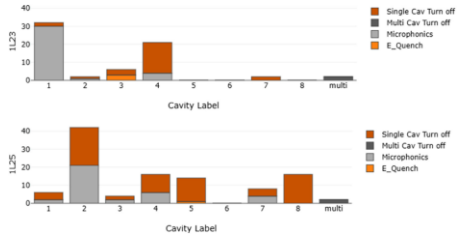
# Topic of Interest

- AI/ML method has the potential to enhance the performance of accelerators (including heavy-ion accelerators) operation by
  - **Optimizing the performance:** surrogate models established from large-scale data that retrieved from the digital diagnostic instruments and simulations
  - **Anomaly detection:** classification and/or unsupervised learning for identify and predicting the outliners
  - **Beam by design:** Tomography of beam distributions, managing/minimizing beam loss
  - **Safety enhancement**: data driven machine protection system

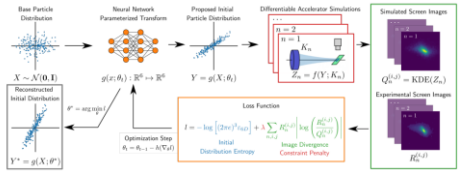



(c) Live 12 quadrupole optimization (d) Simulated 12 quadrupole optimization

Bayesian Optimization of photon energy using 12 quads at LCLS
@ J.Duris, et.al., PRL 124, 124801 (2020)



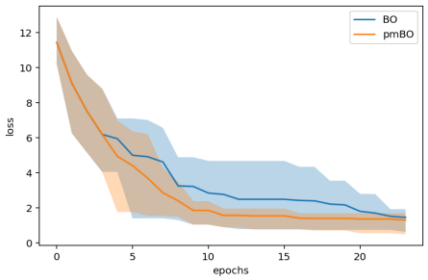

SRF cavity fault classification with ML at J-Lab
@ C. Tennant, et.al., PRAB 23, 114601 (2020)

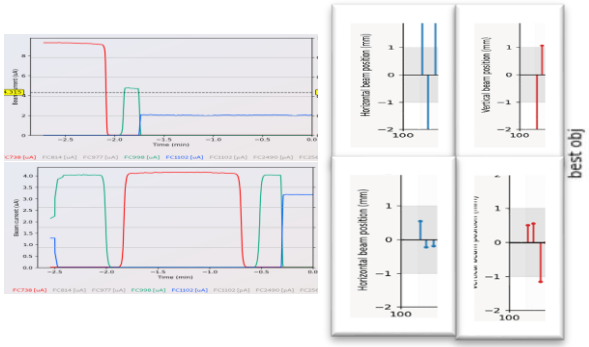


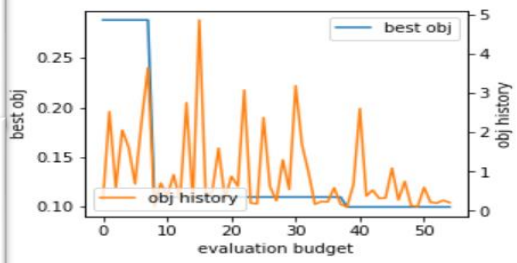
Differentiable-ML based phase space reconstruction at AWA, ANL
@ R. Roussel, et.al., Arxiv 2209.04505(2022)

# Recent Examples

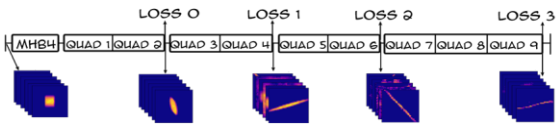
- Prior Mean model assisted Bayesian Optimization (pmBO)
  - Use historical data / simulations to improve the sampling efficiency of BO
  - Proof of principle demonstration using FRIB Frontend.

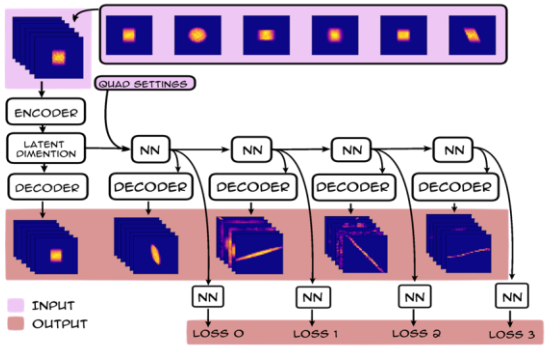


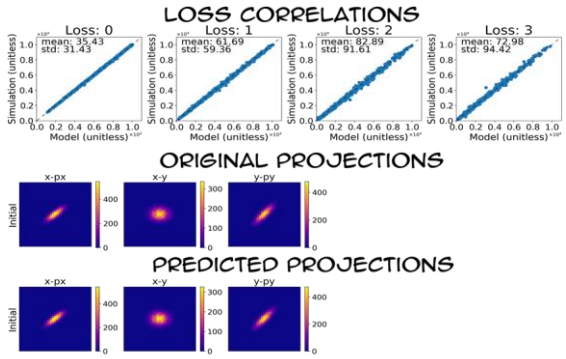






- Beam loss prediction with tomography from beam profiles.
  - Reduce the dimension of beam profile using Autoencoder
  - Combination of 2-D profiles
    - » Various locations
  - Simulation studies



# Challenges and *Expected Advances*

- Challenges:
  - Most successful demonstrated AI/ML cases are within few 10s features. Algorithms for high dimension data are needed to be applied to more complex accelerators or components
  - Most current AL/ML models are lack of explainability. Retraining are usually needed when the machine status is changing. Time-varying systems are generally hard to handle by AI/ML methods.

- Expected Advances:
  - *Demonstration of benefiting points where AI/ML based methods exceed the conventional methods in an accelerator complex.*
    - » *In beam tuning; anomaly detection; controlling beam loss, etc*
  - *Developing Algorithms to reduce the need of experimental data*
    - » *Embed physics/domain information into data-driven model*
    - » *Using prior information, effective transfer learning.*
  - *Effective AI based control method for time-varying system*
  - *Considering the uncertainty in the data driven models and safely apply AI/ML models in operation.*