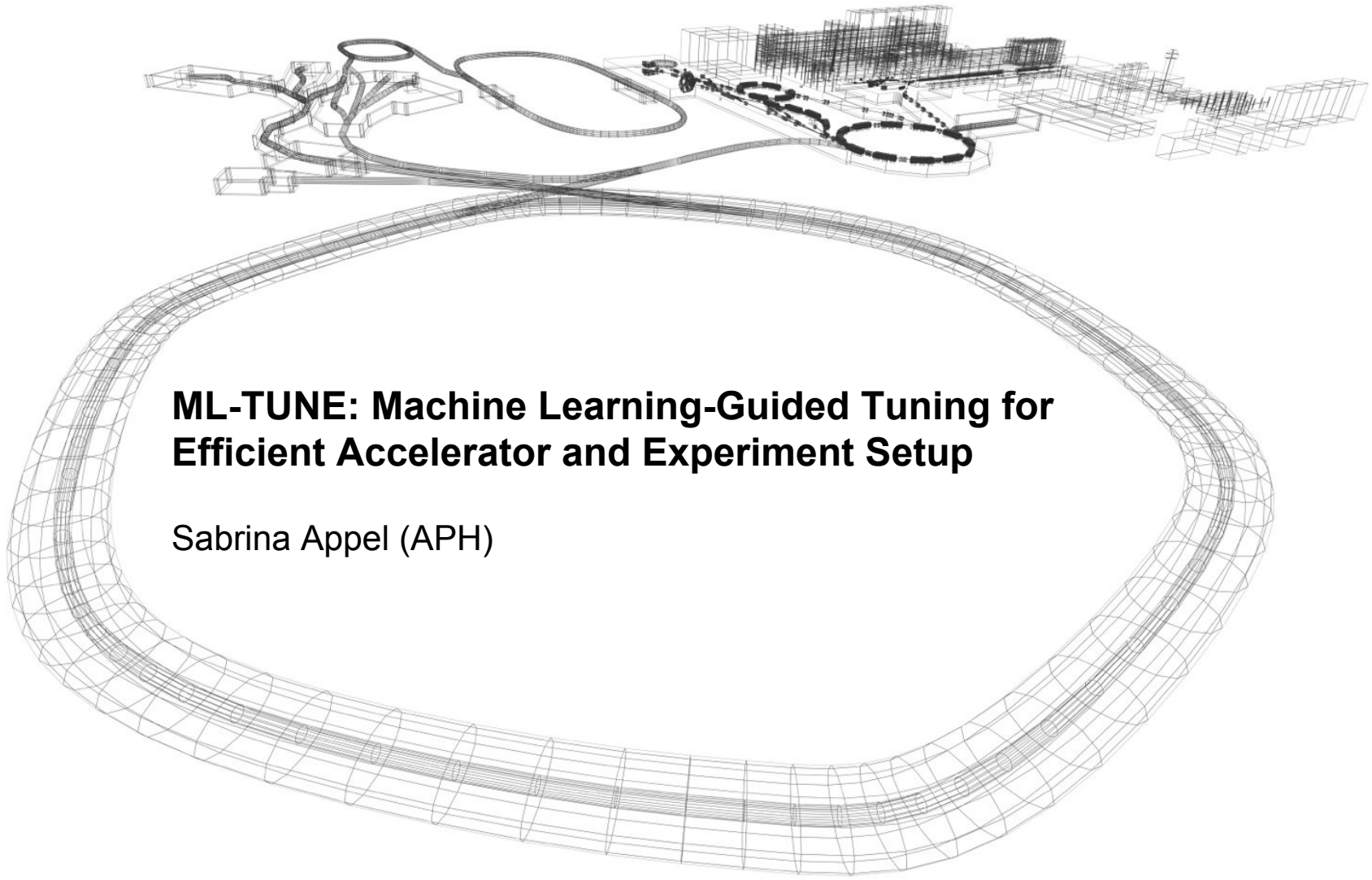
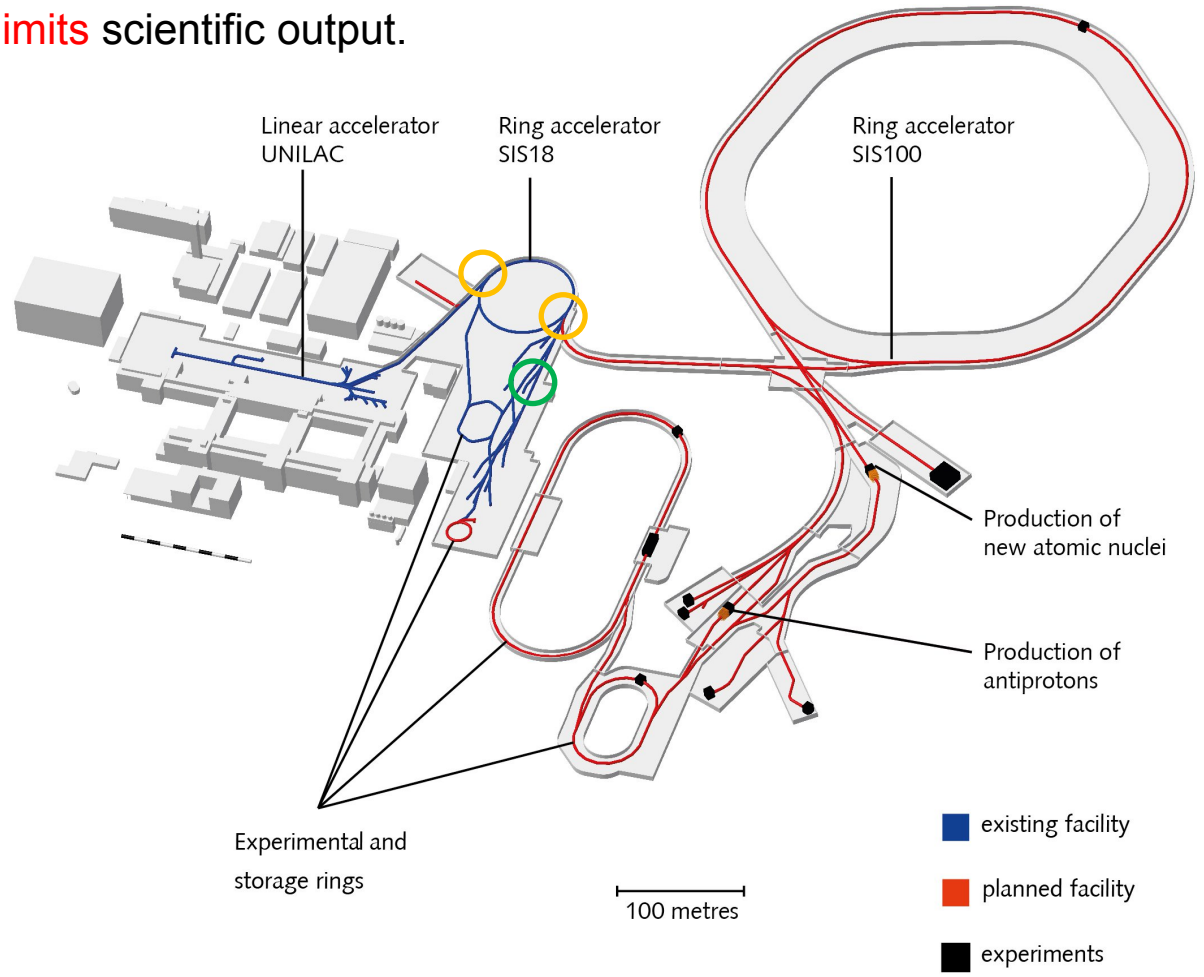


ML-TUNE: Machine Learning-Guided Tuning for Efficient Accelerator and Experiment Setup

Sabrina Appel (APH)

Motivation

- FAIR is entering a crucial phase of commissioning.
- Time for accelerator and experiments setup and tuning directly limits scientific output.
- ML offers new opportunities for automation, decision support, and optimization – not yet widely adopted in accelerator ops.



Research Objectives:

- Reduce Super-FRS setup and tuning time
- Maintain or improve beam quality and transmission
- Improve isotope identification with online ML
- Enable adaptive calibration of detectors and TOF systems

Methods of interests of automation:

- Numerical + Bayesian optimization (BO)
- Physics-information Bayesian optimization
- Multi-Fidelity Bayesian optimization
- Multi-Objective optimization with BO
- Data-driven model predictive control
- Reinforcement learning

Current Status & Approach

Automation of operational tasks essential for accelerators and experiments

- **Impact on the efficiency of data collecting**

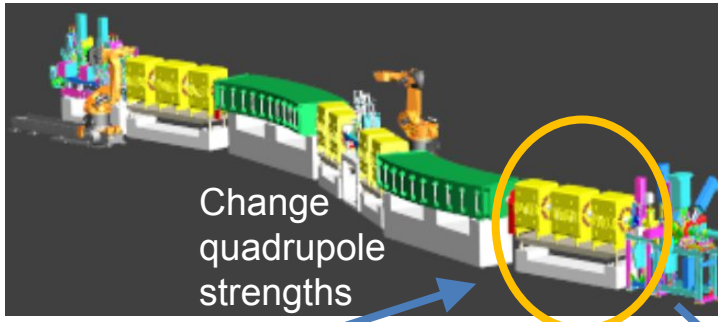
Higher-order ion-optical model of the Super-FRS
(based on real magnet data)

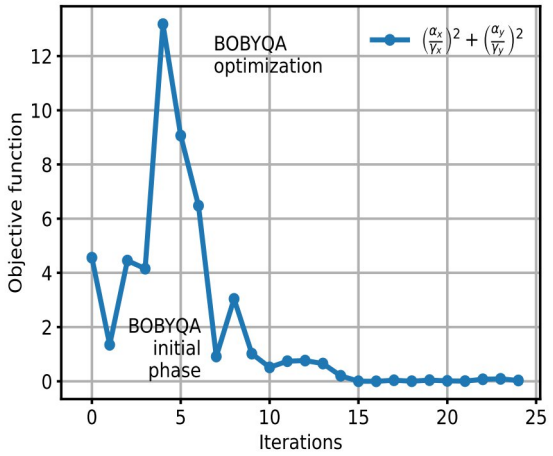
- Physics-aware (multi-fidelity) Bayesian optimization
  fast simulations + online measurements
- ML models (surrogates) pre-trained by physics models

First success at SIS18 + FRS (online)

- Improve injection optimization
- Steer at FRS target
  and focus beam afterwards
- Grouped into beam spots using a
  classification algorithm
- Improved goal function with ML for
  quad/sextupole tuning in development

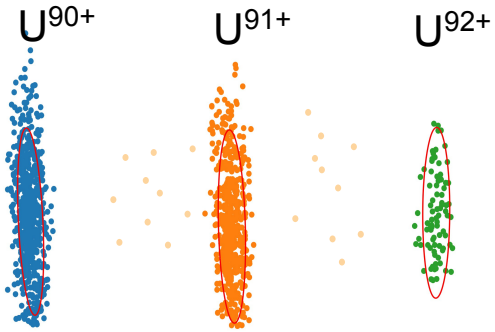
Schematic illustration of FRS Dispersive Focus area





TPC Data analysis

Evaluation
of beam
spot slope



Generic Optimization Frontend & Framework (GeOFF)

- Modern ML research is centered around Python (e.g., TensorFlow, PyTorch).
  - (Limited ML ecosystem in Java hindered broader adoption)

- Individual Python-based efforts led to duplicated work, incompatibilities, and poor usability.

Preprint: arxiv:2506.03796
Paper submitted to SoftwareX

GeOFF

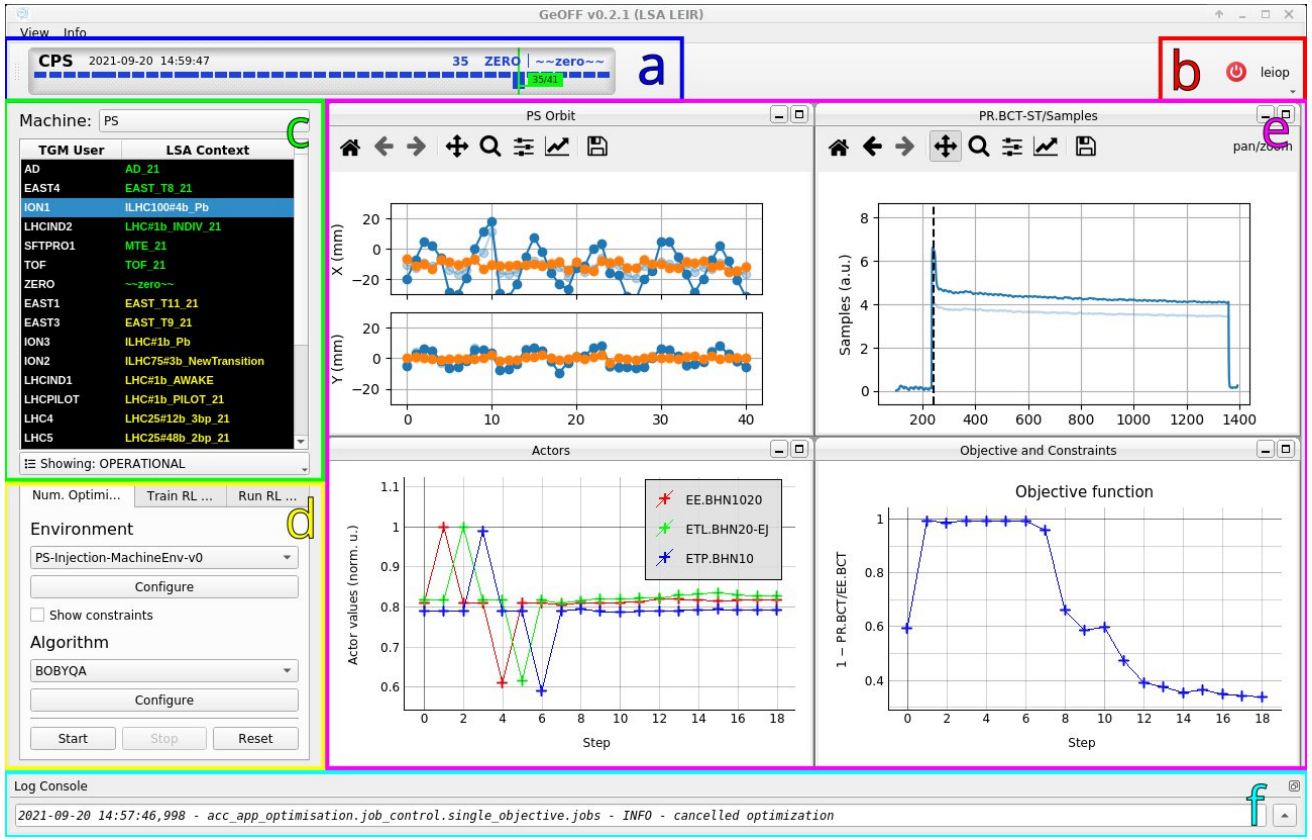
- Standardized API for optimization and RL to enable easy sharing and comparison (d)
  - Problems formulated as environment (allow optimization of very complex problems)

- Utility library to reduce redundant work (e.g. for live plotting, e)

- GUI app for easy use in the control room (a, c, f)
  - Can be used also in simulation (w, w/o GUI)

- Supports RBAC for secure remote access (b)
  - Enables **remote guidance** & **hands-on training; Based on simulation and online interaction**

- Open-source, developed by GSI & CERN (Euro-Labs)



Summary

ML-TUNE will:

- Save valuable beam time
- Improve robustness and reproducibility due to ML integration
- Enables remote guidance & hands-on training
  - Based on simulation and online interaction
- Super-FRS is an ideal demonstrator for automation of accelerators and experiments setup
- Open-source tools ensure wide impact

Partner institutions

GSI (lead) – accelerator automation, shared ML framework (Geoff),
TU Darmstadt – experts on AI automation
CERN – Geoff, accelerator automation

Budget Request: 1 PhD position (3 years, TVöD E13) plus travel, Total: ~€300,000 (incl. overhead),
Infra provided by GSI