Automated Optimization of Machine Parameters at the European XFEL

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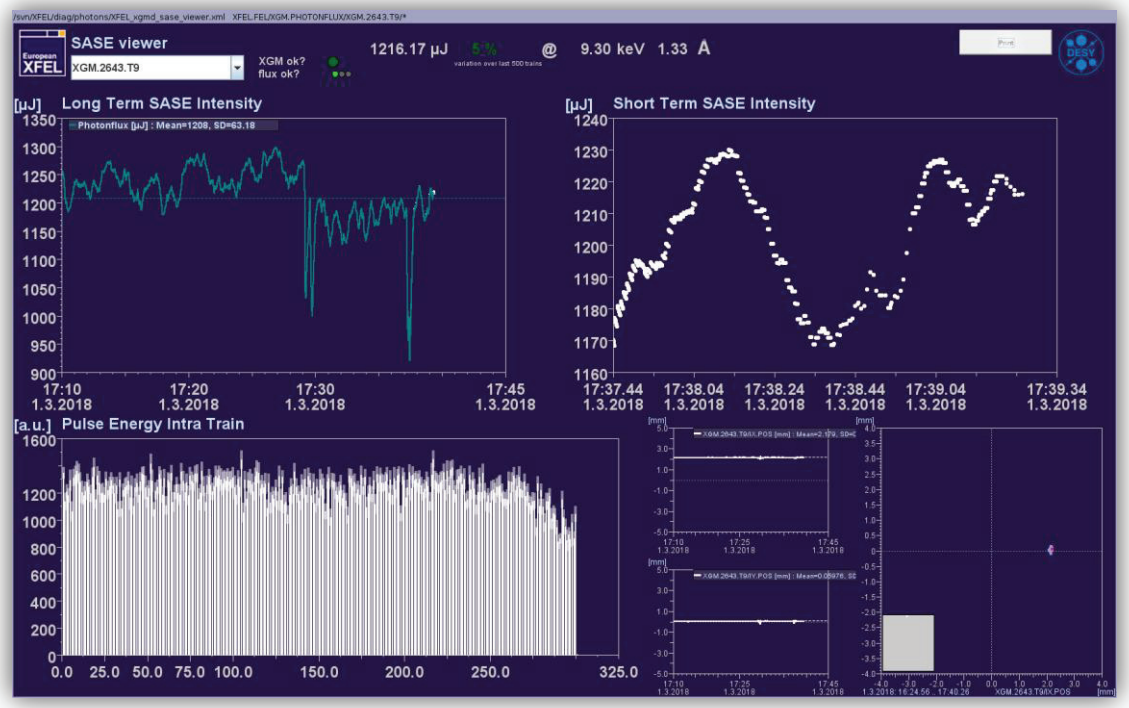
Outline

- Introduction
- Generic Optimizer
- Adaptive Trajectory Feedback
- Further Optimization Options
- Machine Learning: First Steps
- Conclusion

Introduction

- FEL tuning: Fundamentally important for operation
- Manual tuning: Time-consuming and tedious
- What do we need?
  - Understand machine & physics
  - Tools for automatic optimization (model-independent and model-dependent)



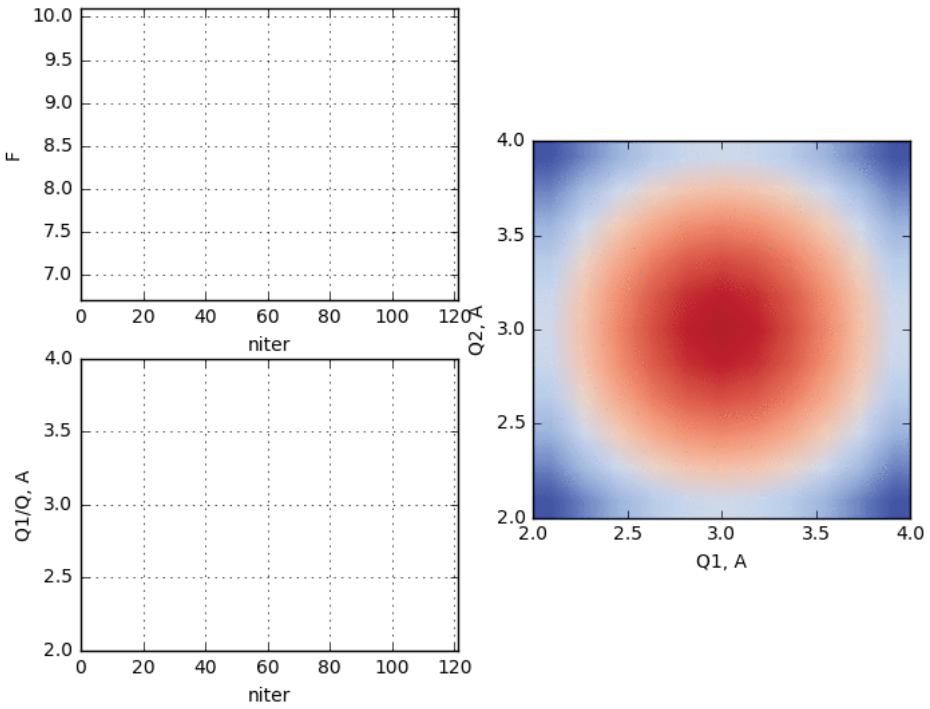
Ocelot Project

- Started as simulation project (undulator radiation, FEL) at European XFEL
  I. Agapov et al., NIM A 768, 2014
- Developed beam dynamics module (linear optics, collective effects, second order effects, optimization techniques)
  S.Tomin et al., WEPAB031, IPAC2017
- Everything in **Python**. Focus on simplicity. Implement only physics.
- Turned into more on-line control-oriented development
  arXiv:1704.02335
- Open source (On GitHub **https://github.com/ocelot-collab/ocelot**)

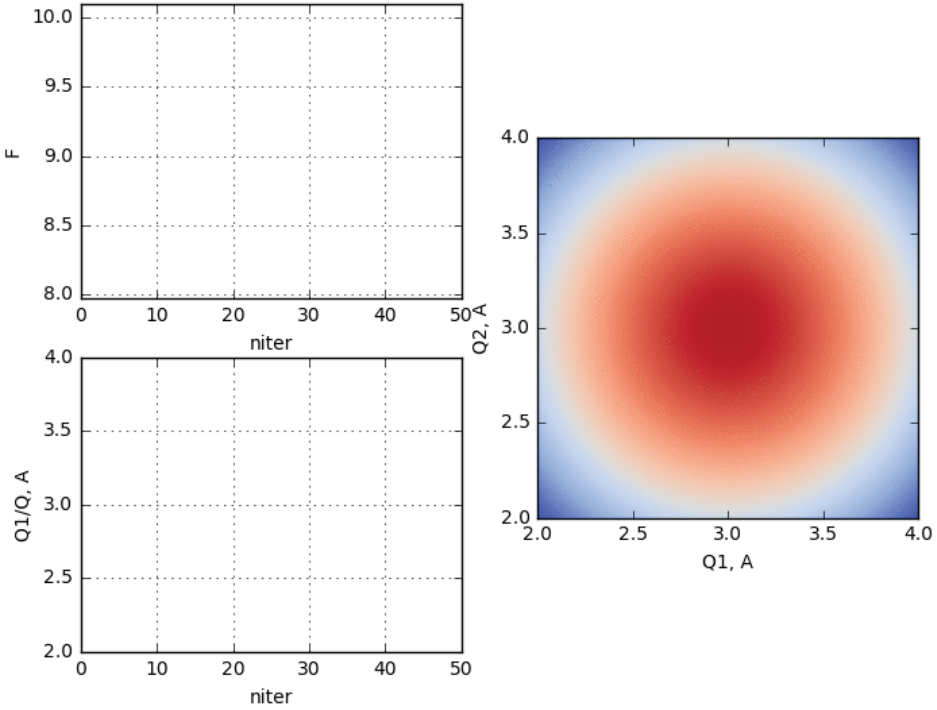
Ocelot Generic Optimizer

Generic Optimizer: Idea

Scanning



Optimization Algorithm – Simplex

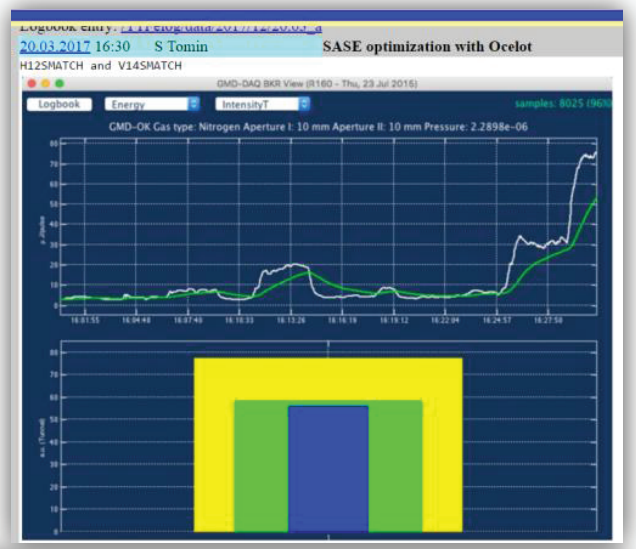


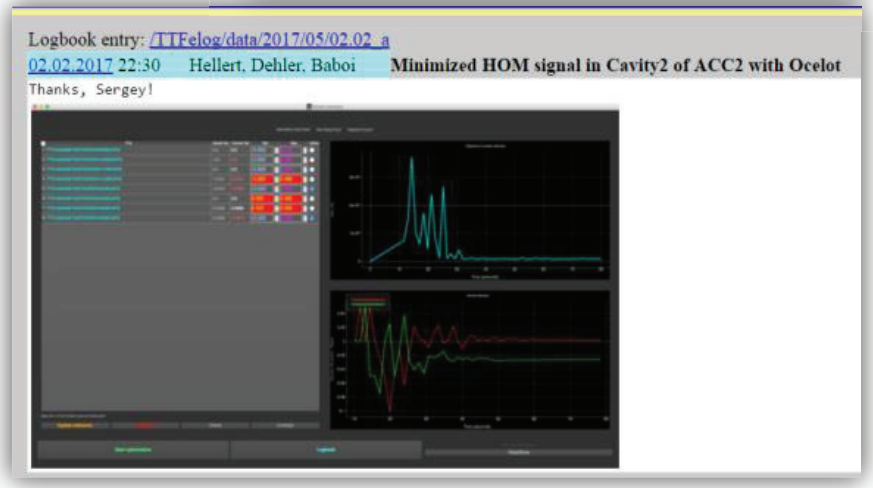
Generic Optimizer: History

- First demonstration at FLASH
  I. Agapov et al., TUPWA037, IPAC2015
- Initial implementation for fixed tasks
- However development shifted towards making the tool fully configurable and useful for ad-hoc tasks
- Deployed at European XFEL and FLASH

Generic Optimizer: Use Cases

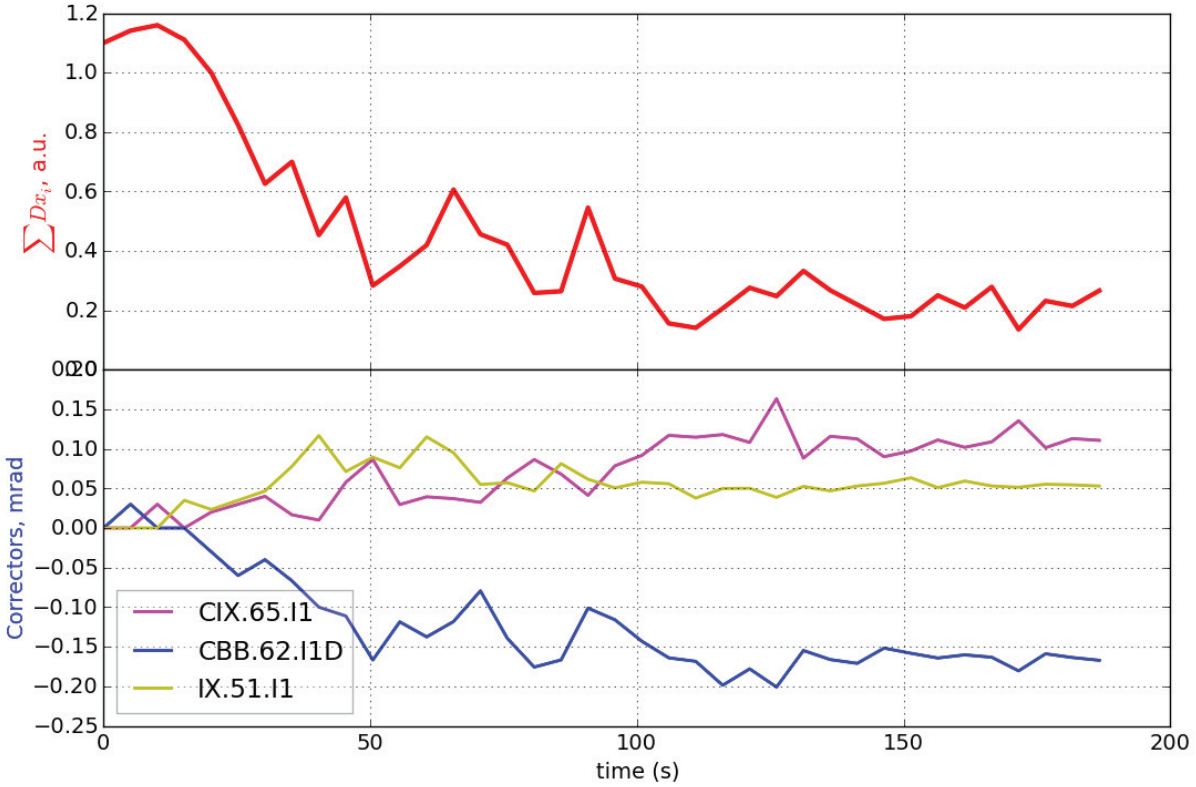
- FEL power maximization (FLASH)
- Minimization of beam losses while keeping a reasonable orbit in the main dump beamline (XFEL)
- Orbit distortion compensation with air coils in an undulator section (XFEL)
- Minimization of HOM (higher order mode) signal in an accelerator module (FLASH)



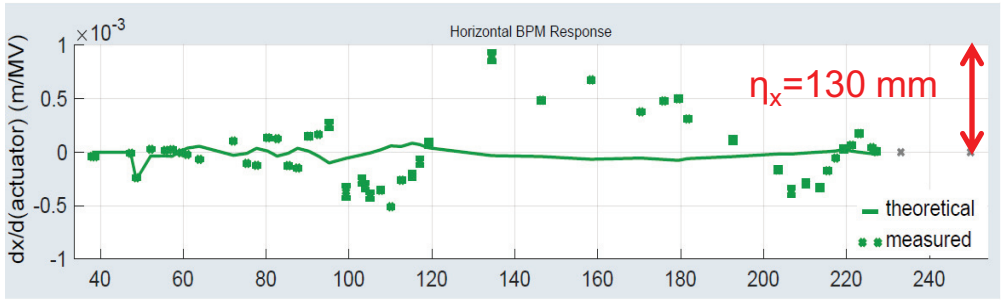


Generic Optimizer: Local Dispersion Correction

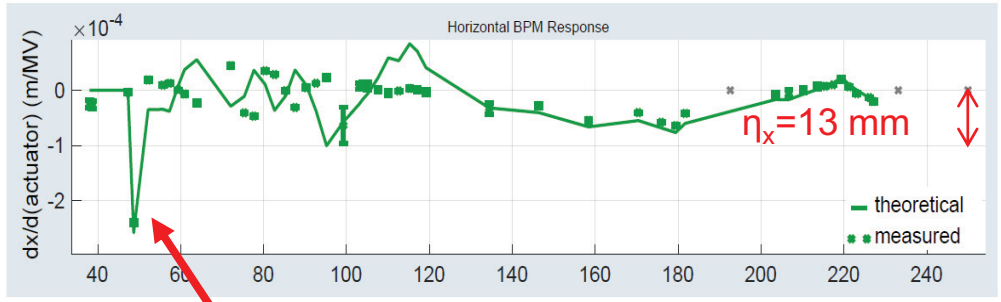
Horizontal spurious dispersion correction with 3 corrector magnets.



Before correction



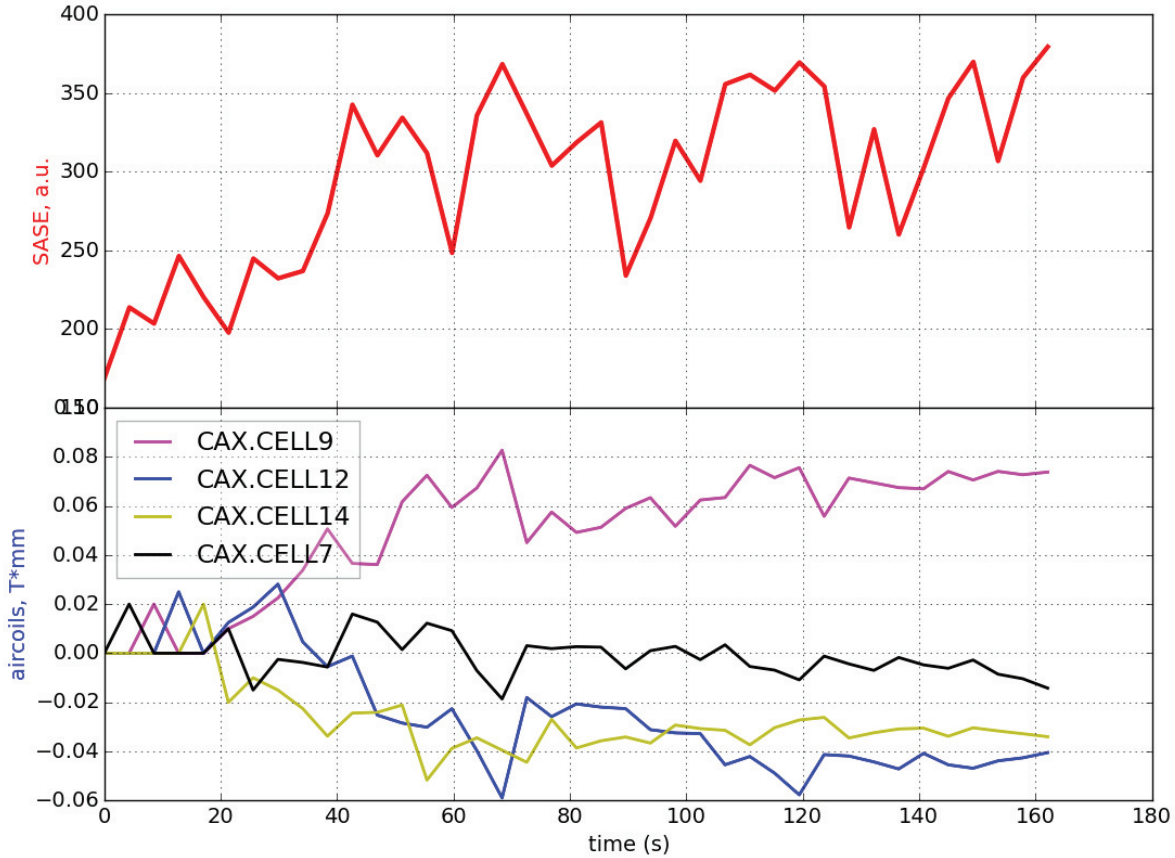
After correction



Laser Heater chicane

Generic Optimizer: FEL Optimization

- Air coils between the undulator cells were used to optimize the SASE signal
- Up to 6 air coils are typically used at the same time.



Generic Optimizer: Plans

- Gaussian process method* for SASE optimization is implemented but not tested at European XFEL
- Merging SLAC and XFEL versions of OCELOT optimizer to one in collaboration with SLAC (in progress)
- Other collaborations?

* M. McIntire et al., “Bayesian Optimization of FEL Performance”, IPAC2016

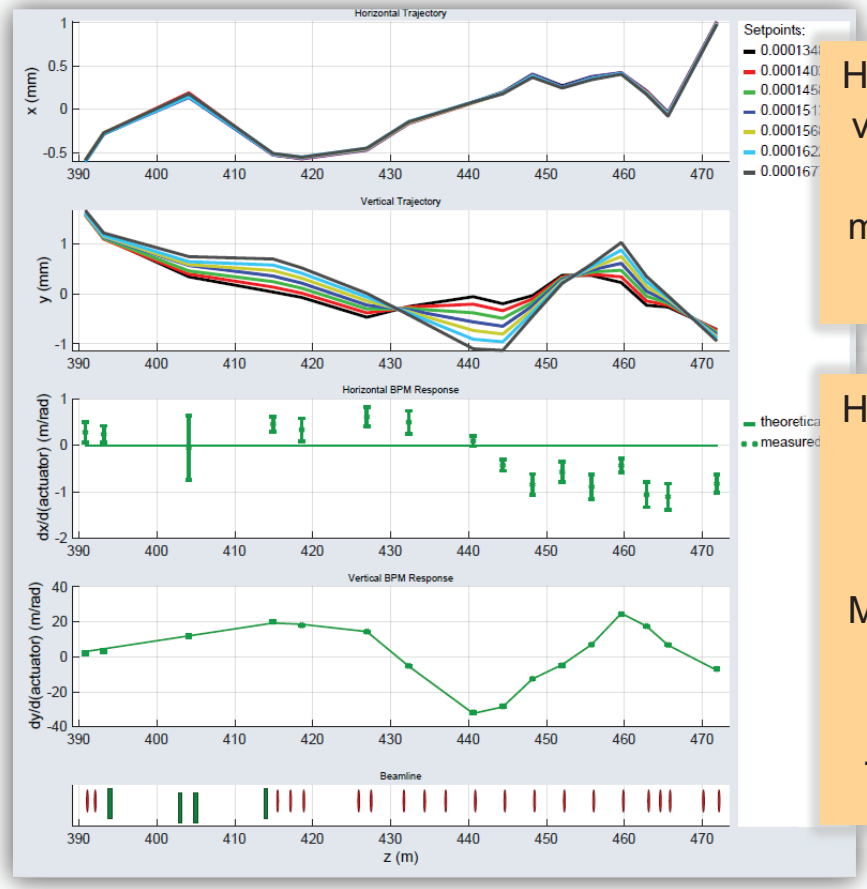
Ocelot Orbit Correction Tool with Adaptive Feedback

Orbit Correction Tool with Adaptive Feedback: Infrastructure

- Good online magnet model
  - Full hysteresis curve (lookup table) available for almost all magnet types
  - Magnet control via strength / deflection angle / k value
- Excellent agreement between theoretical and measured trajectory responses

➔ Orbit correction can use theoretical response matrices (recalculated if optics changed).

Trajectory response measurement using a vertical corrector.



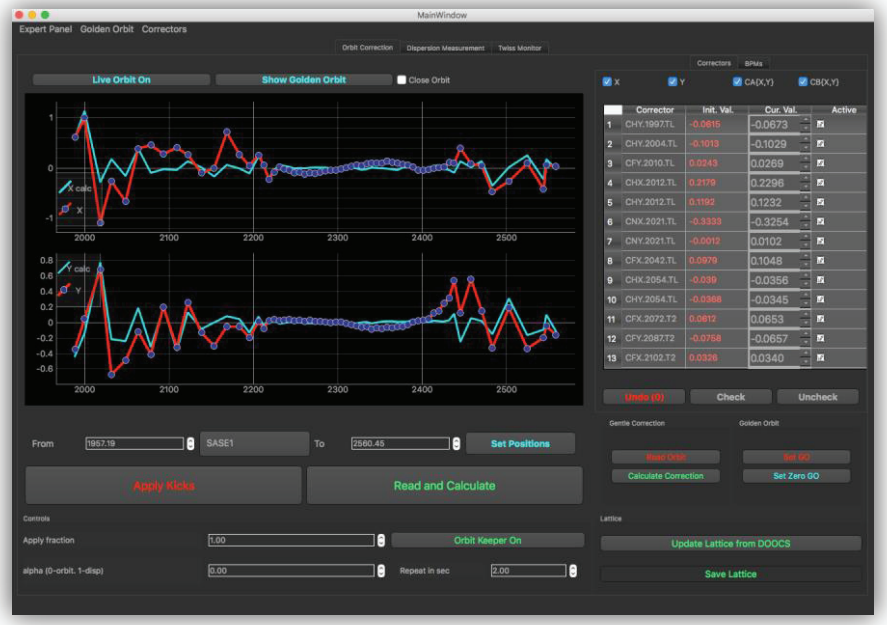
Horizontal and vertical orbits of all measurement steps

Horizontal and vertical trajectory responses. Measurement -> Dots Theory -> Solid line

Orbit Correction Tool with Adaptive Feedback

- Ocelot orbit correction: Standard tool for trajectory correction (SVD algorithm)
- Adaptive feedback: Continuous correction of undulator orbit to optimize SASE pulse energy

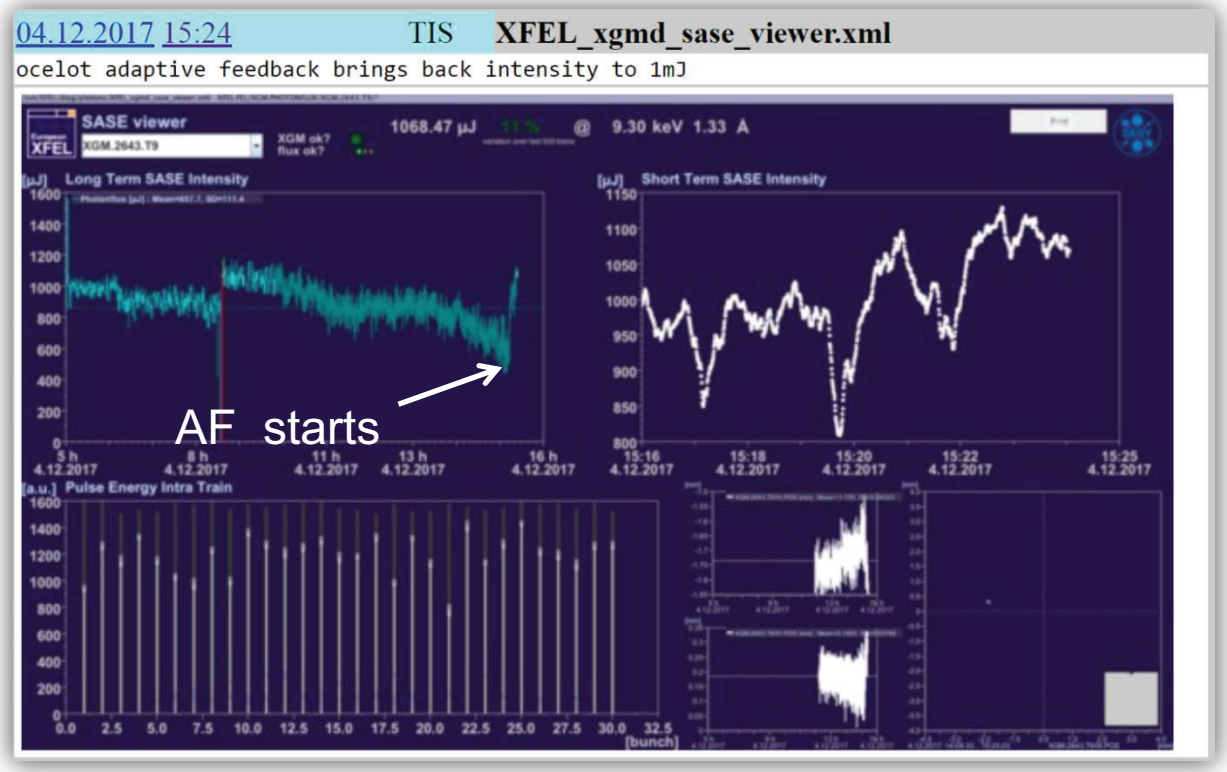
Orbit correction tool GUI



Adaptive Feedback GUI

Adaptive Feedback: Algorithm

- Inspired by automatic optimizers at Fermi*
- Collect ~300–700 trajectories and corresponding FEL pulse energies
- Sort trajectories according to pulse energy
- Calculate new golden orbit from the trajectories with the highest pulse energy
- Correct to golden orbit



* G. Gaio, M. Lonza, “Automatic FEL Optimization at FERMI”, ICALEPCS2015

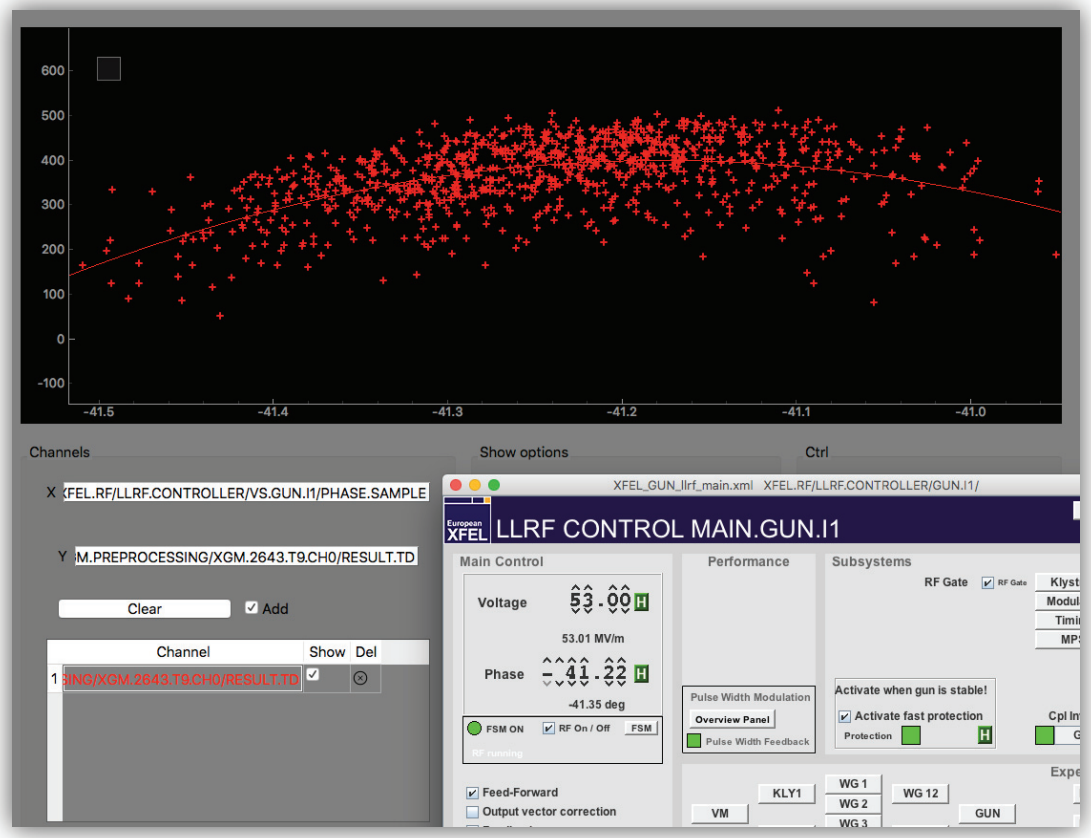
Adaptive Feedback: Operational Remarks

- In a user run (November 20 – December 5, 2017), the adaptive feedback was used **233 times** for a total working time of **Σ 89 hours.**
- Typically optimizes of the trajectory upstream of the undulator (“launch”)
- Can change pointing of the FEL
- Optimizes mean FEL output power (average over all bunches of a train)
- Orbit over pulse train can now be stabilized via fast intra-bunchtrain feedback

More Optimization Options

More Optimization Options

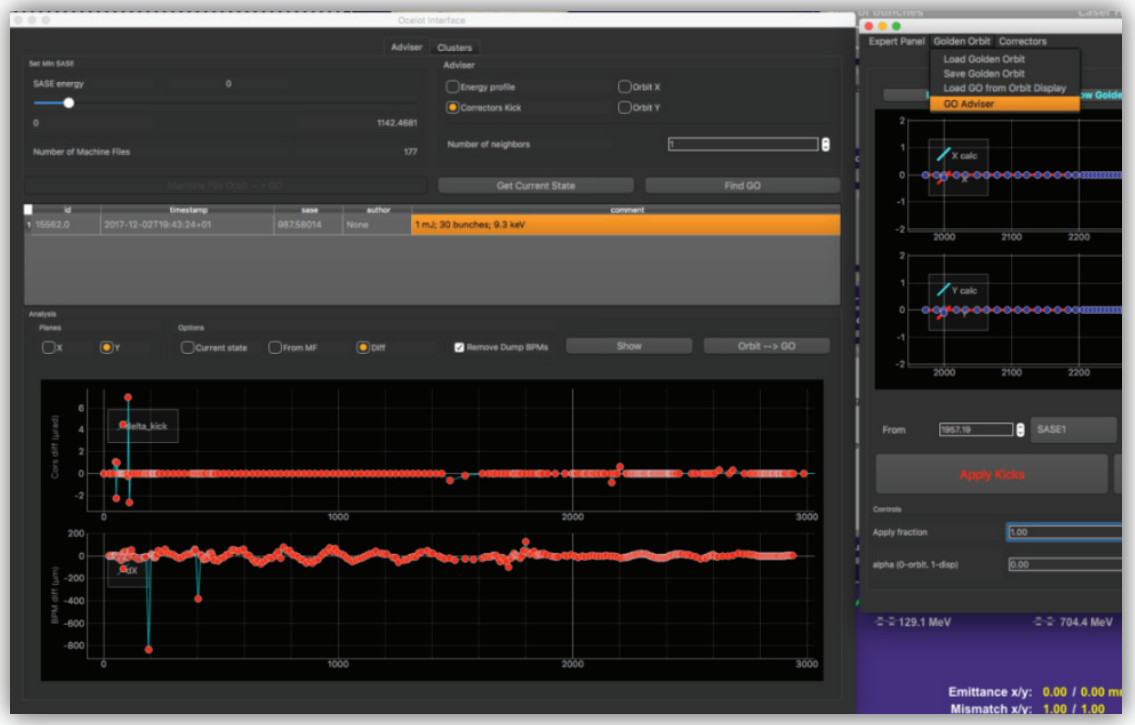
- Automatically exploit correlations
  - Machine jitter is often sufficient
  - So far: observed & corrected by hand
- → Discussion



Machine Learning: First Steps

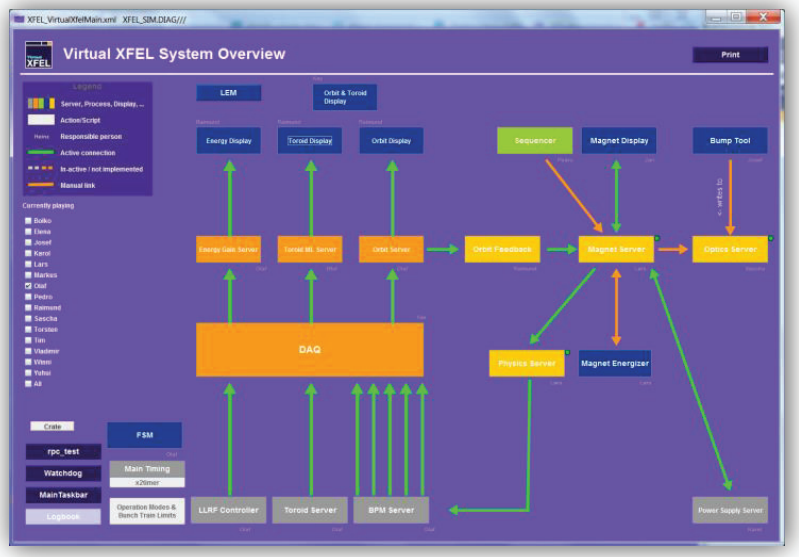
Golden Orbit Adviser

- Experimental option in Ocelot orbit correction tool
- Find machine files that are “as close as possible” to the current machine setup
  - In terms of energy profile, corrector kicks, or hor./vert. trajectory
- Uses “nearest neighbors” ML method



Idea: Generate a Fake FEL Signal on the Virtual XFEL

- Virtual XFEL* is environment for testing high level controls and applications
- Virtual XFEL has a physics server to simulate electron trajectories at 10 Hz reprate
- Testbed for physics codes (e.g. orbit correction, BBA)
- Can we simulate FEL signal with machine learning algorithms to test optimizers & automatic tuning tools?
  - Collect data during real machine setup & FEL tuning
  - Train neural network
  - Use neural network to generate FEL signal in Virtual XFEL



* R. Kammering et al, The Virtual European XFEL Accelerator, TUD3O04, ICALEPCS2015

Conclusion & Outlook

Conclusion & Outlook

- Ocelot-based tools: In daily use at the European XFEL
  - Generic optimizer: Many fields of use
  - Adaptive trajectory feedback: FEL tuning
  - Plan: Test new optimization methods (GP, extremum seeking, …)
  - Plan: Merge XFEL and SLAC optimizer versions
- Other tuning aids
  - Implement automatic feedbacks based on correlations
- Machine Learning
  - First steps – no “killer application” yet
  - Need to invest in infrastructure & make data accessible (DBs, event recognition)
  - Looking for promising applications