Experience with automated optimization of machine parameters

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Intelligent Controls for Particle Accelerators
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Outline

Introduction

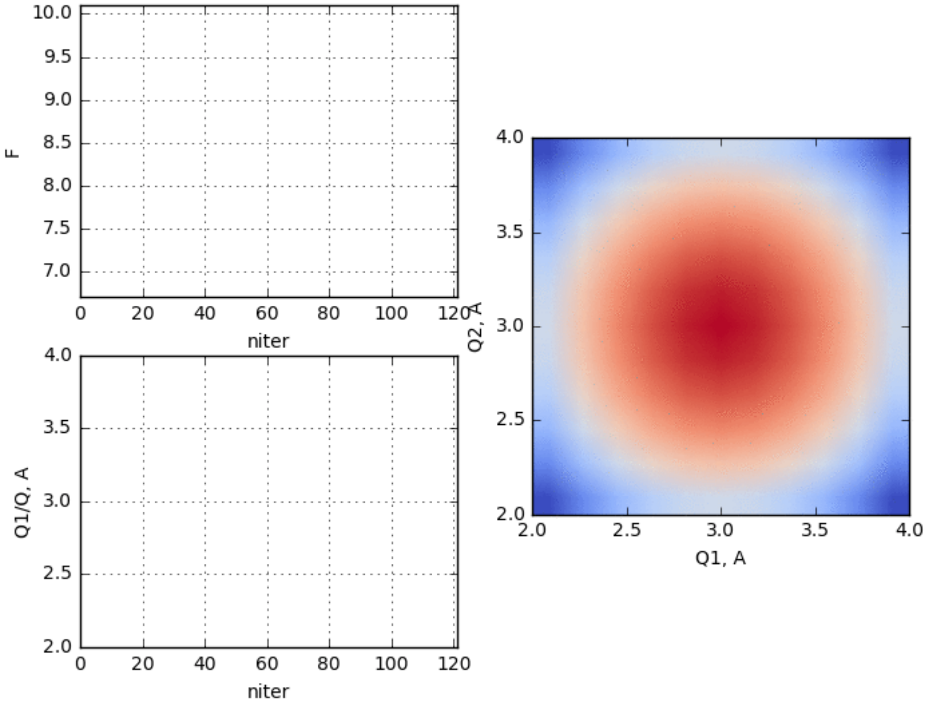
- FEL tuning: Fundamentally important for operation!
- However: lengthy and tedious when done manually.
- Human expertise is required for top performance **but:** automatic tuning helps a lot
- What do we need?
  - Tools for automatic optimization (model-independent and model-dependent).
  - Some parameters are hidden, understanding of the machine and physics behind it is crucial for getting even better performance:
    - ► Online model
    - ► Machine learning.

OCELOT Generic optimizer

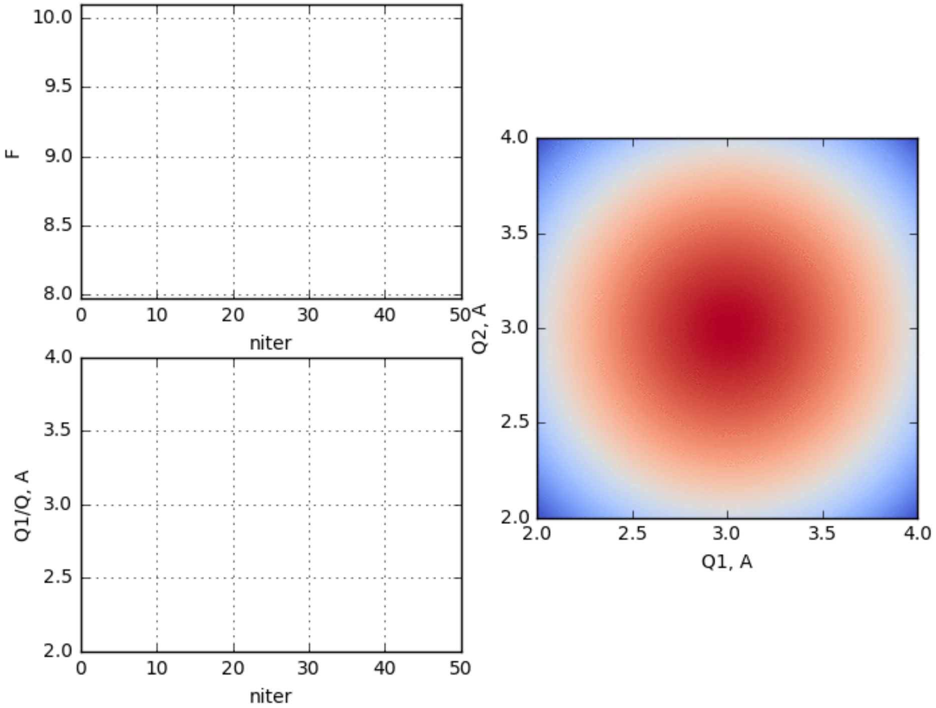
- OCELOT project
  - Started as simulation project (Undulator radiation, FEL) at European XFEL.
    Agapov et al., NIM A. 768 2014
  - Beam dynamics module was developed (linear optics, collective effects, second order effects, optim. techniques).
    S.Tomin et al. WEPAB031
  - Everything in **Python**. 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**)

Generic optimizer. Idea

Scanning



Optim. Algorithm - Simplex

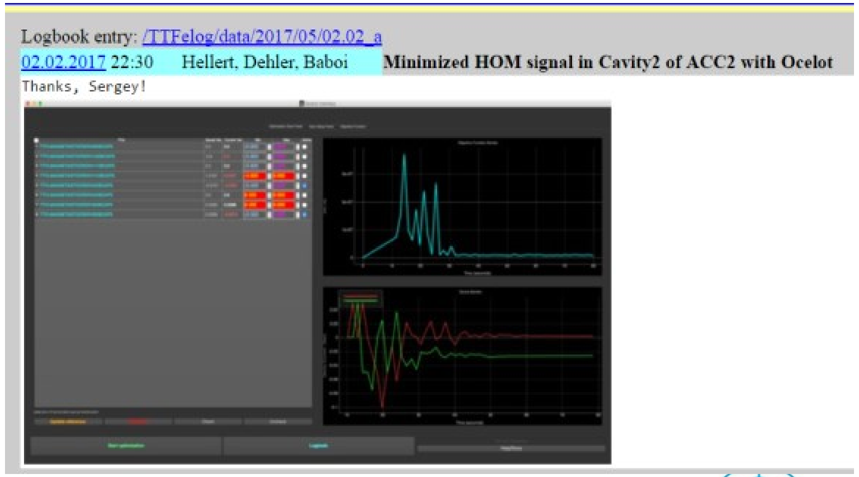


Generic optimizer

- First demonstration at FLASH. *I. Agapov et al. TUPWA037 IPAC15*
- Sequence of actions implemented initially
- However development shifted towards making the tool more universal and useful for ad-hoc tasks
- Deployed for European XFEL and FLASH.

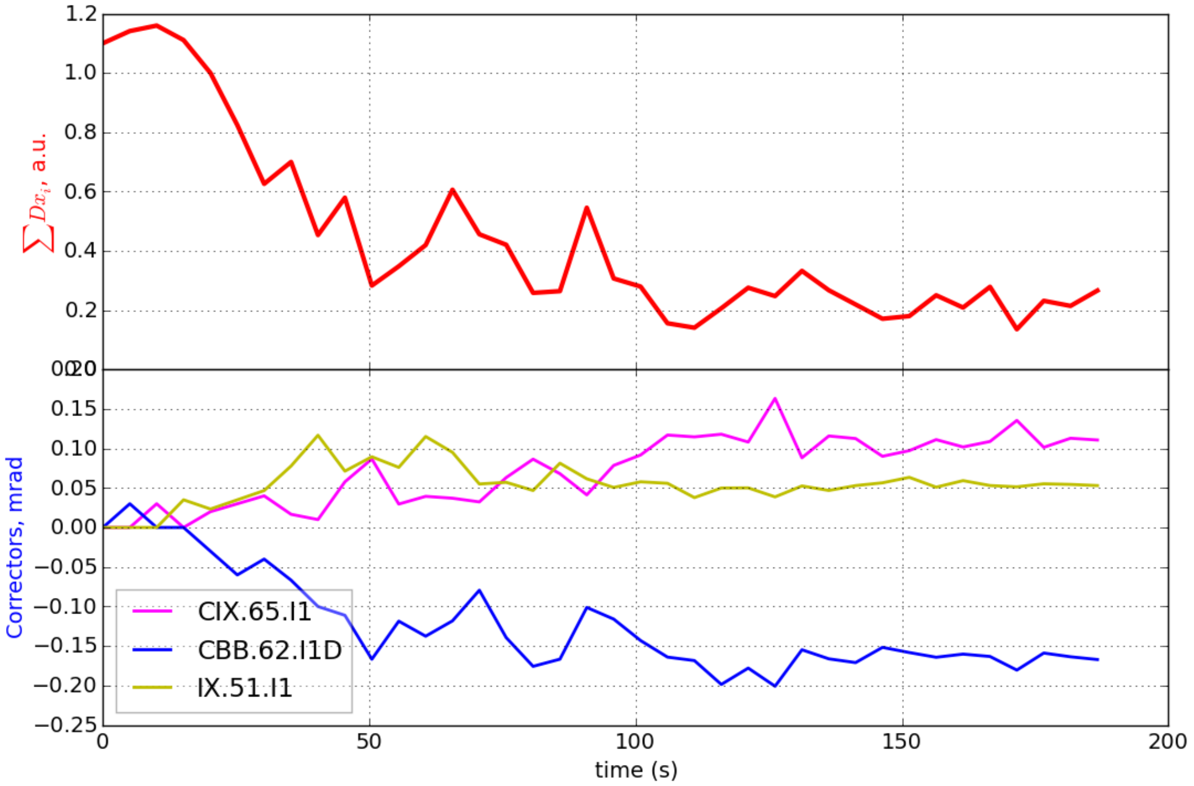
Generic optimizer: Use cases

- Several different customized variants of the optimizer were used only a few times for different tasks.
- Examples for earlier customized setups:
  - Minimization of beam losses while keeping a reasonable orbit in the main dump beamline.
  - Orbit distortion compensation with air coils in an undulator section.
  - Minimization of HOM (higher order mode) signal in an accelerator module (FLASH).
  - SASE maximization (FLASH).

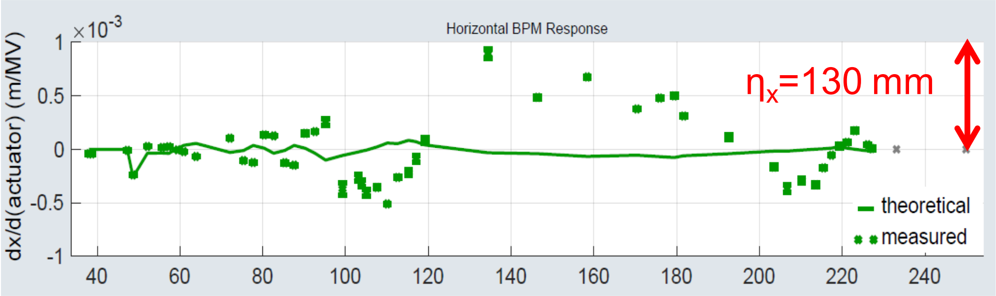


Generic optimizer: local dispersion correction

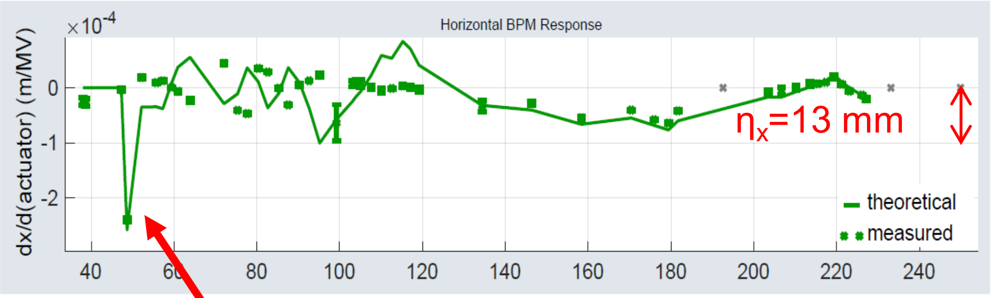
Horizontal spurious dispersion correction with 3 corrector magnets.



Before correction



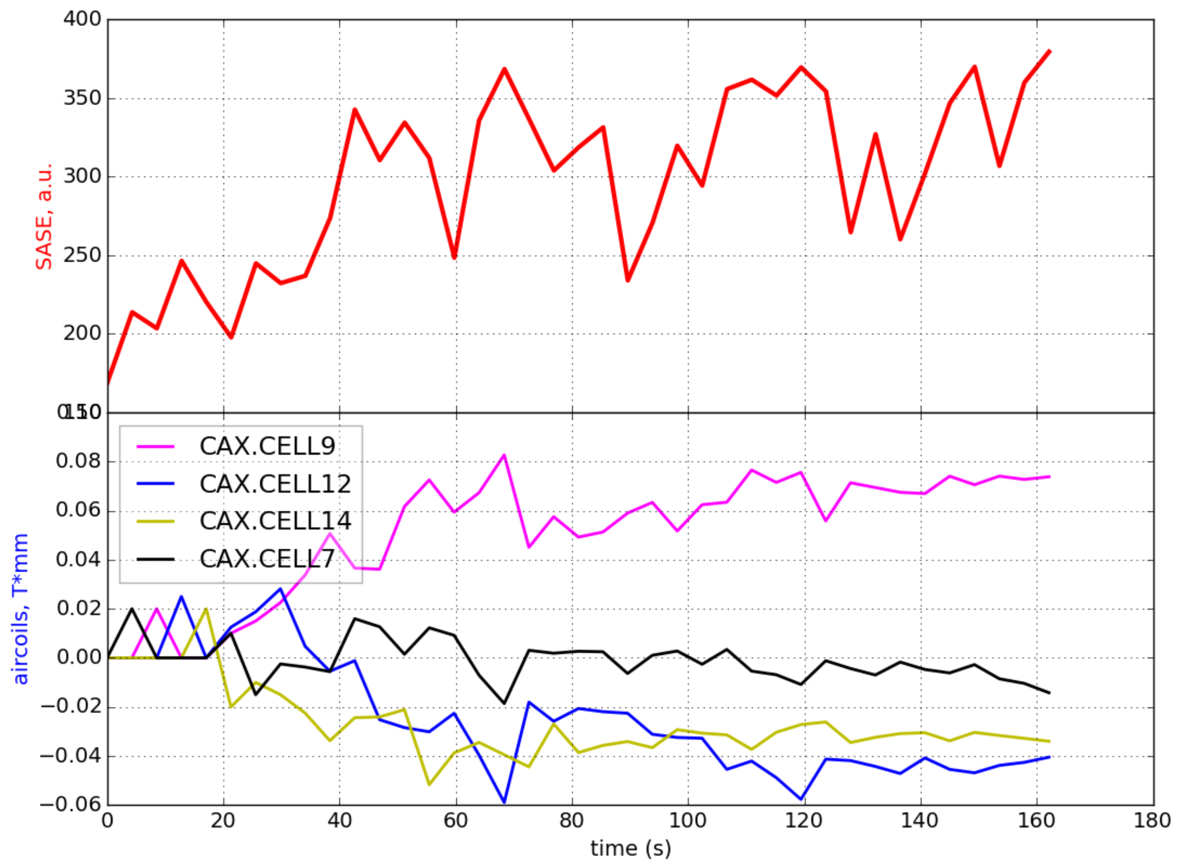
After correction



Laser Heater chicane

Generic optimizer: SASE 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

- GP 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)

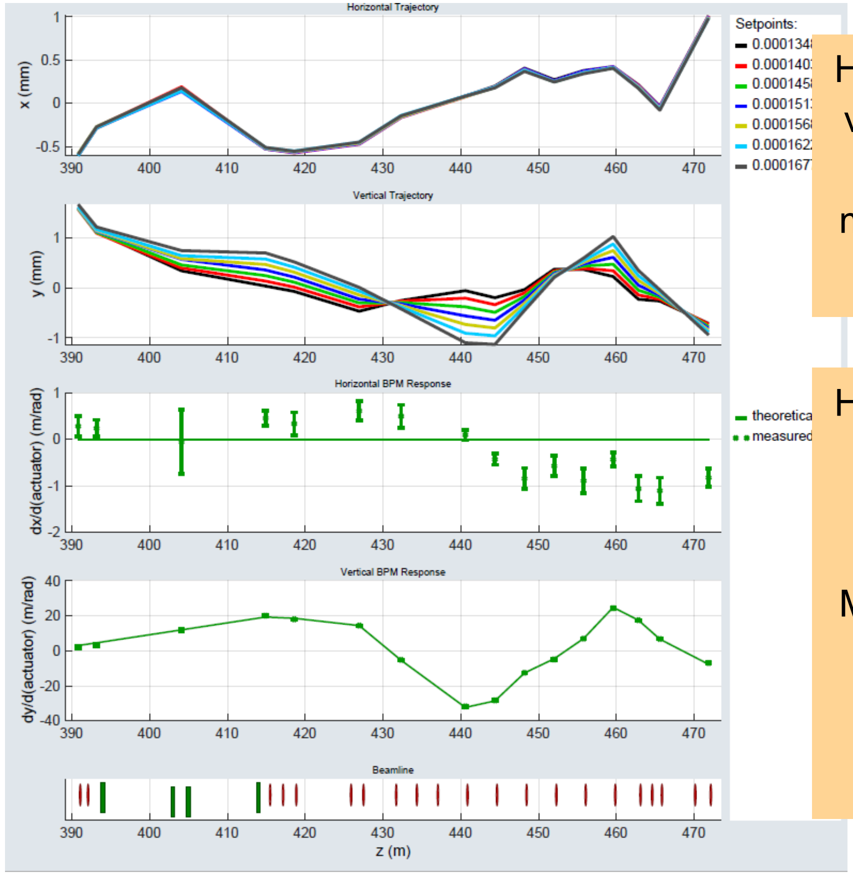
* M. McIntire, et al. Baysian Optimization of FEL Performance at, IPAC2016

OCELOT orbit correction tool with adaptive feedback

Orbit correction tool with adaptive feedback. Infrastructure

- A very sophisticated magnet model leads to a good agreement between theoretical and measured trajectory responses.
- Thus the orbit correction tool can use theoretical response matrices which can be recalculated if optics is changed.
  - Each magnet type was measured at DESY before installation.
  - A hysteresis curve or lookup table for each magnet is implemented in the magnet ML server.
  - Tools work with kicks instead of currents what significantly speed up the application development.

Trajectory response measurement using a vertical corrector.



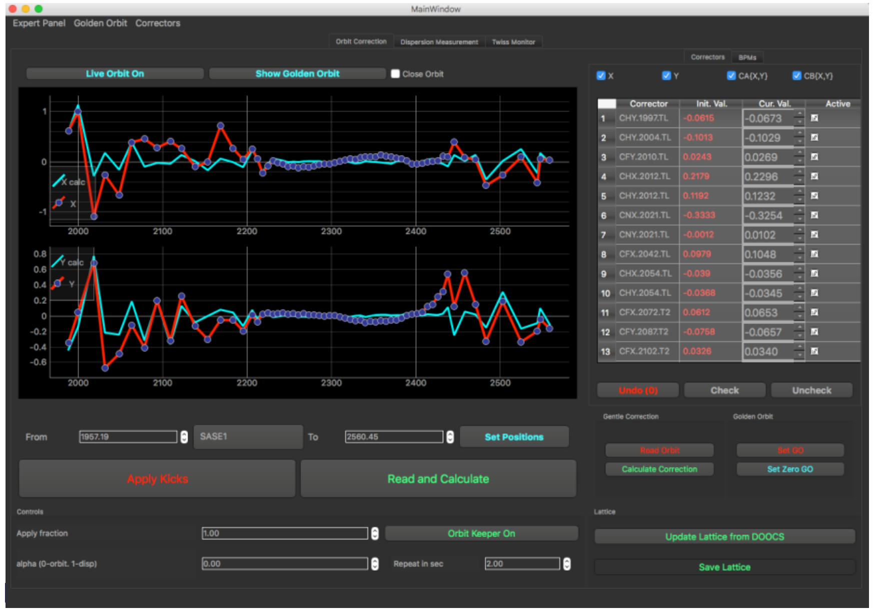
Horizontal and vertical orbits of all measurement steps

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

Orbit correction tool with adaptive feedback.

- OCELOT orbit correction is the standard tool for orbit correction (using SVD algorithm).
- The adaptive feedback is a part of the orbit correction tool. It is used currently for an continuous orbit correction upstream the undulator to optimize the SASE pulse energy.

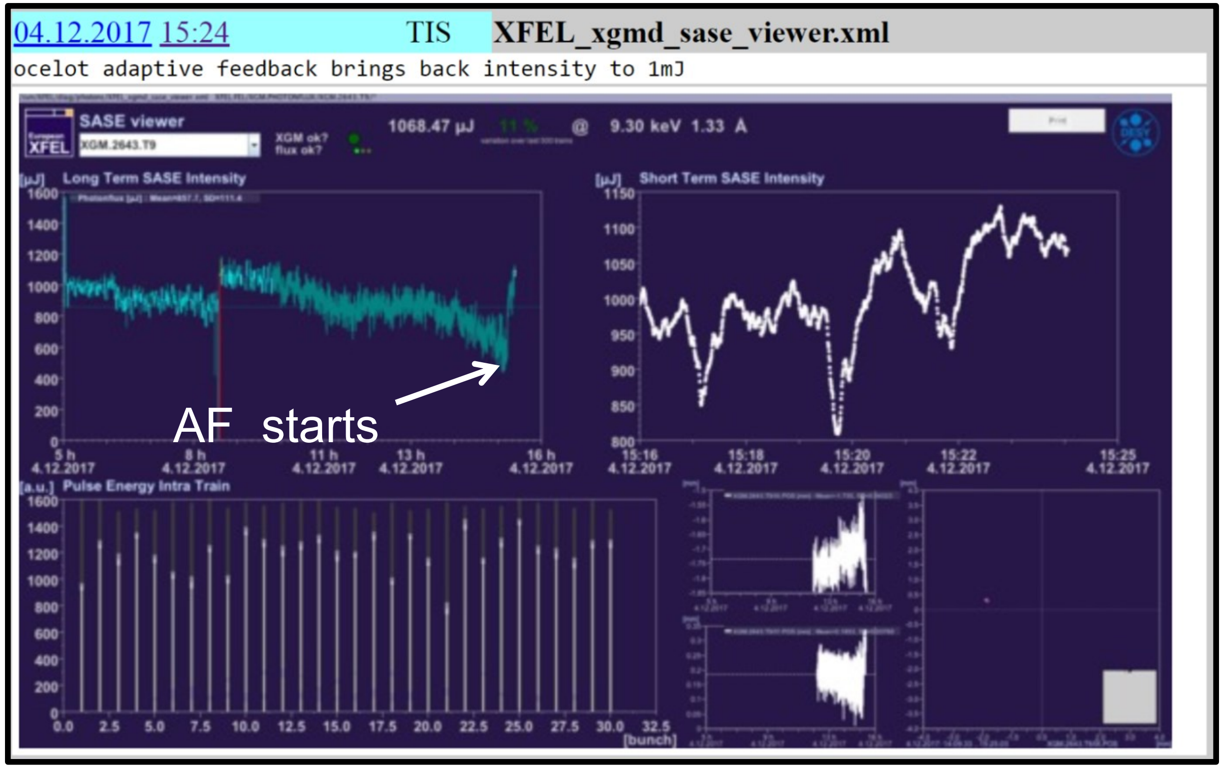
Orbit correction tool GUI



Adaptive Feedback GUI

Adaptive feedback

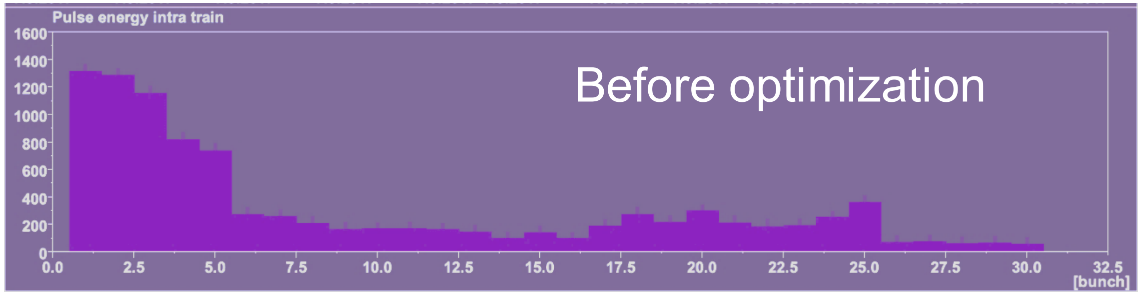
- Algorithm of Adaptive Feedback*
  - Shot-to-shot collection of orbits (~ 300 - 700) and the corresponding SASE pulse energy.
  - Sorting orbits according to SASE energy.
  - Taking 10-20% of the orbit with highest SASE and calculating new golden orbit for the feedback.

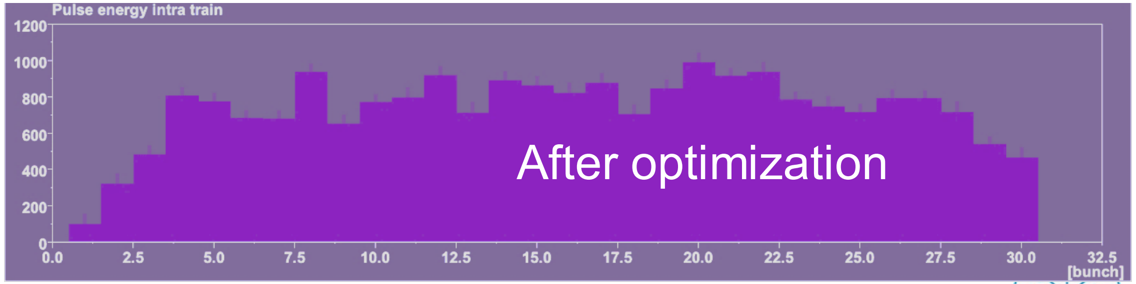


*Idea from: G. Gaio, M. Lonza, Automatic FEL Optimization at FERMI, Proc. of ICALEPCS2015

Adaptive feedback

- Optimization of the orbit upstream the undulator. Only first three bunches were lasing before optimization. The IBFB was not commissioned at that time. Thus not all bunches were on the same orbit.
- The adaptive feedback optimizes by default the averaged SASE signal over all bunches in one bunch train. However, it is also possible to optimize for dedicated bunches if required.
- The lasing of the first bunches was suppressed but all following bunches contributed to the SASE level after the optimization with the adaptive feedback.



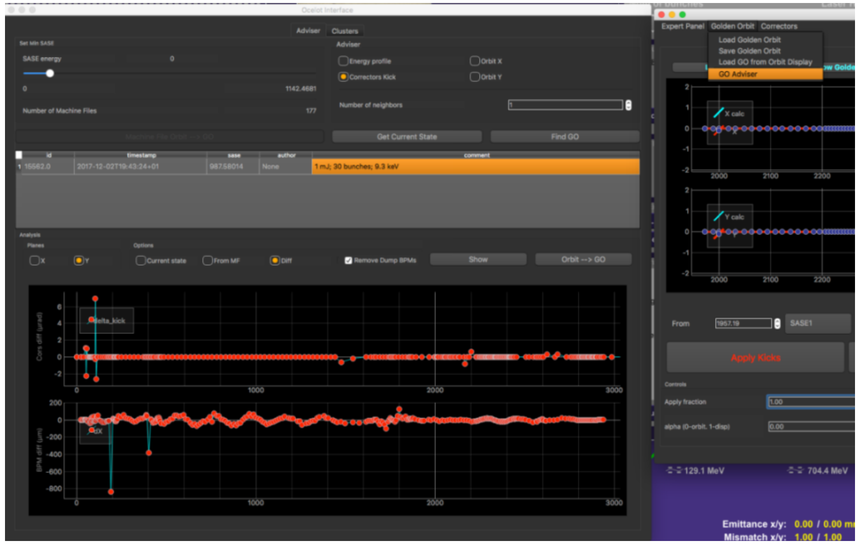


During User Run (November 20 - December 5) Adaptive feedback was used 233 times and total working time Σ 89 hours

Machine Learning at European XFEL

Golden Orbit Adviser

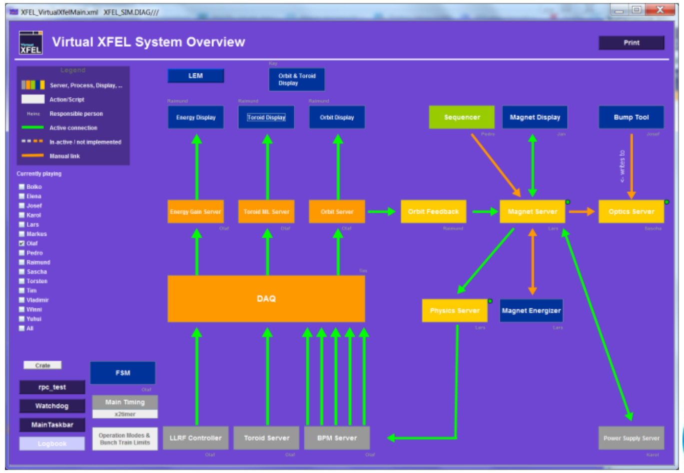
- Recently we introduced to the Ocelot orbit correction tool a "Golden orbit adviser" (in test mode).
- The idea is to find the machine file in the database that is as close as possible to the current machine setup.
- For instance, you can select as a reference vector the corrector kicks (or beam orbit in X/Y plane) and ML method (Nearest Neighbors) will find the machine file with the corrector kicks (or orbit) closest to the current conditions.



Virtual XFEL with SASE signal for optimization methods studies (plans)

- Virtual XFEL* is environment for testing high level controls and applications
- Virtual XFEL has a physics server to simulate e-orbit with 10 Hz rep rate, what allows physics experiments to some extent (orbit correction, BBA).

- Idea is to extend VEXFEL capabilities to generate SASE signal for studies of optimization and automatics tuning methods
  - Collecting data during real machine setup, SASE tuning
  - Training NN
  - Using NN to generate SASE signal in VEXFEL

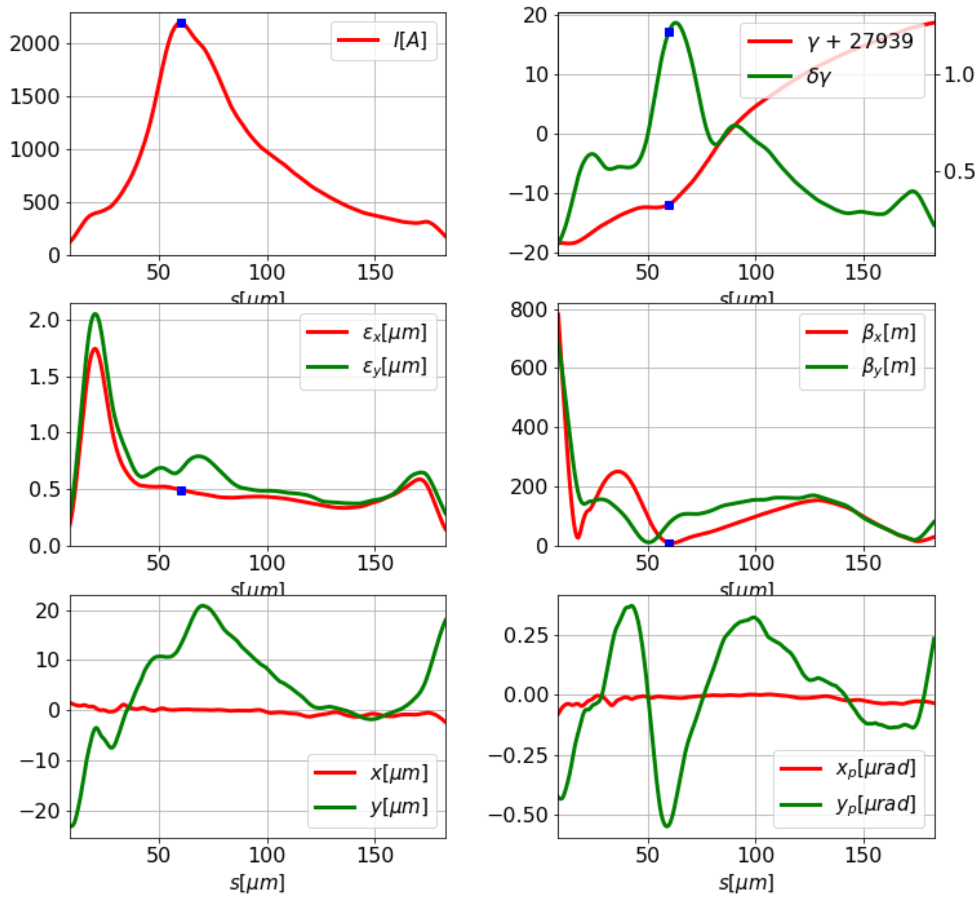


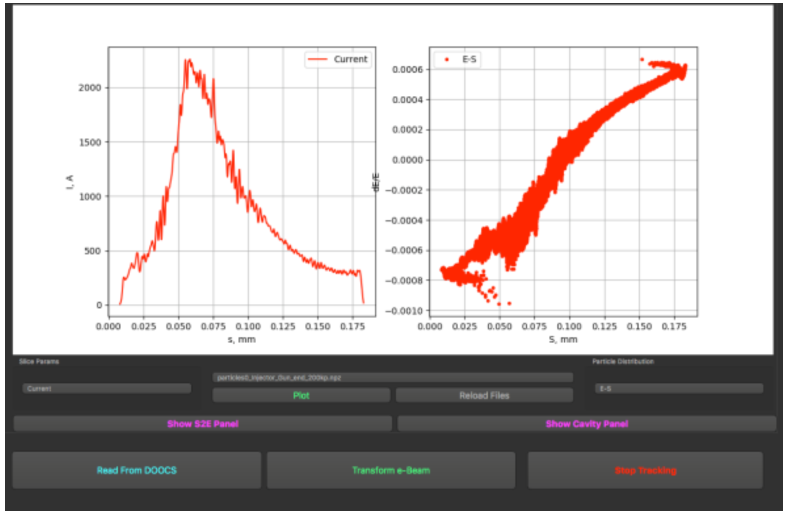
*R. Kammering et al, The Virtual European XFEL Accelrator, TUD3O04, ICALEPCS2015

S2e simulations in control room
Online model

OCELOT toolkit: S2E in control room

- Reading quads and cavities settings and measured beta-functions
- Tracking 200000 particles with CSR, SC, wakes through all machine up to undulator section
- Total time calculation 20 mins

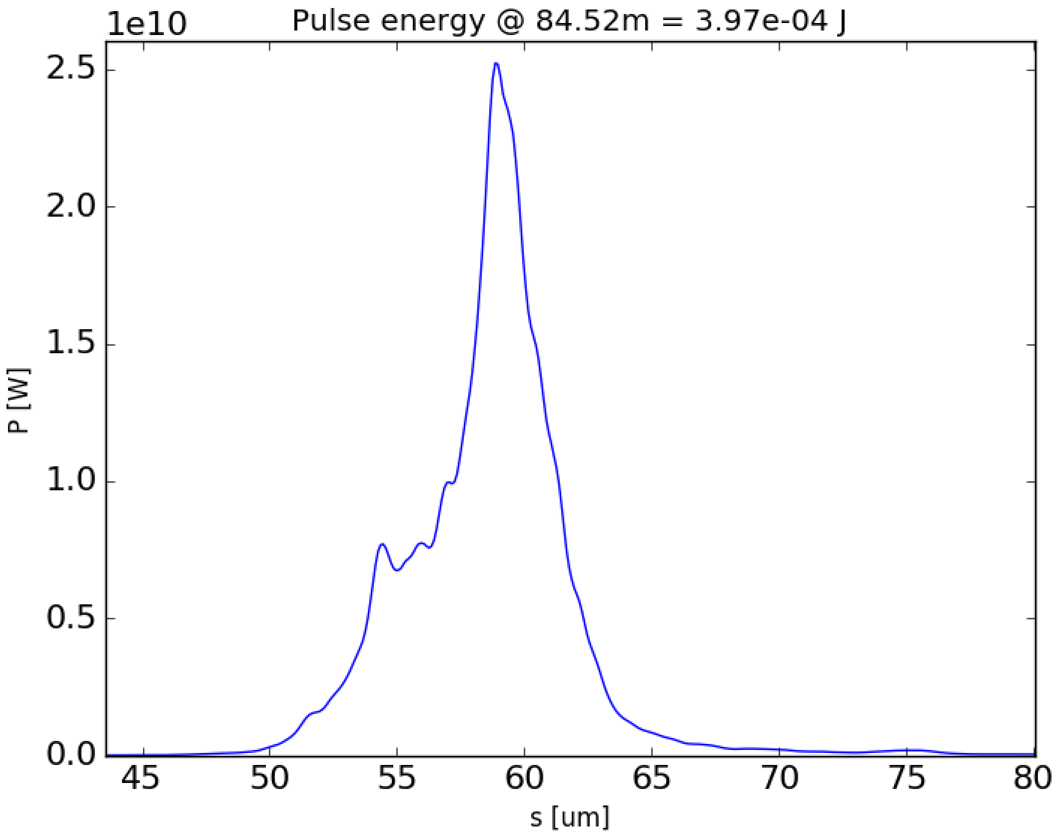




Coauthors: M.Dohlus, I.Zagorodnov

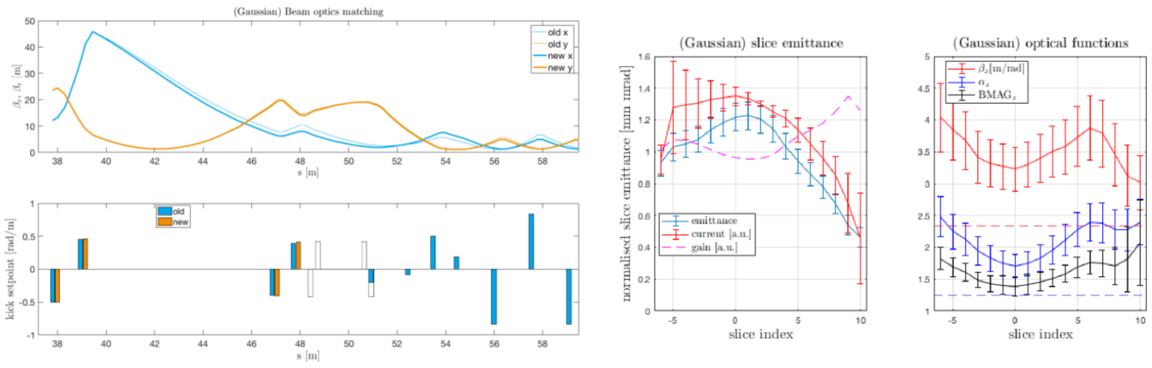
OCELOT toolkit: S2E in control room

- FEL power Estimator (Ming Xie parametrization). – 0.4 mJ
- In reality, we had 1 mJ with nonlinear undulator tapering
- Genesis can be used as well, however infrastructure to cluster is needed



Authors: G.Geloni, S.Serkez

Can we improve online model?



Beta-function /emittances/slice parameters measurement

- 4-screen method (can be made without interruption of photon beam delivery)
- Quad-scan
- TDS

Courtesy by M.Scholz, B. Beutner

Single particle optics measurements

- Kick the beam by two correctors
- fitting elements of TM
- Track twiss parameters through machine using design or measured beta-function
- Time measurement ~ 2 mins
- TM can be used in other tools

Courtesy by F.Brinker

Conclusion

- OCELOT optimization is a part of the daily European XFEL operation
  - Plans: testing of new optimization method (GP, extremum seeking, …), merging the XFEL and SLAC optimizer versions.
- R&D of the accelerator online model and S2E simulations (including FEL process) in control room:
  - Reduce calculation time in 10 - 20 times (from 20 mins to …) optimize algorithms, using GPU/clusters…
  - Connect online model to reality → measurement / control / simulations
- Machine Learning in operation and optimization
  - the investment in infrastructure is needed (DBs, events recognition)

…so, thanks to all the people who contributed to this work (commissioning teams, colleagues etc)

…and thank you for your attention!