Status of Automated Optimization Procedures at The European XFEL Accelerator

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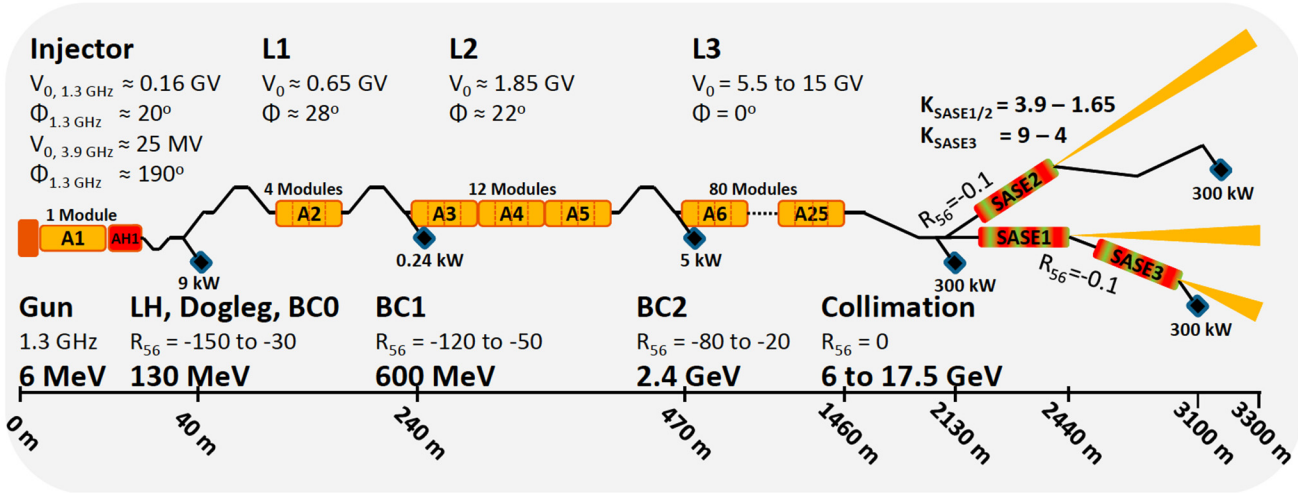
Outline

- Accelerator overview
- Motivation
- OCELOT Optimizer
- OCELOT “Adaptive” Feedback
- Conclusion & Outlook

Accelerator Overview



- Electron beam energy up to 17.5 GeV
- Pulse rep. rate 10 Hz
- Bunches per pulse 2700
- Intratrain rep. rate 4.5 MHz
- Bunch charge 0.02 – 1 nC

- Electron bunches in a single pulse are distributed by a fast kicker system to three SASE undulators

W. Decking et al, "Commissioning of the European XFEL", https://doi.org/10.18429/JACoW-IPAC2017-MOXAA1

Motivation

- Modern Free Electron Lasers are complex facilities with hundreds of free tuning parameters
  - Bunch compression, orbit, beam optics, gun optimization, undulator gaps, phase-shifters, etc

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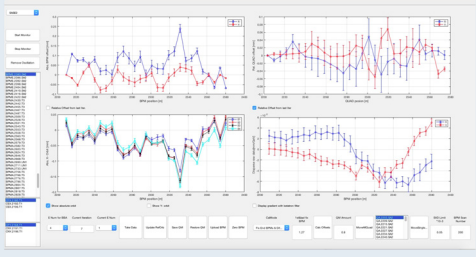
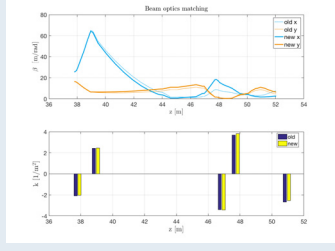
- Modern Free Electron Lasers are complex facilities with hundreds of free tuning parameters
  - Bunch compression, orbit, beam optics, gun optimization, undulator gaps, phase-shifters, etc
- Even when the main accelerator systems work well, manual fine-tuning is necessary to get the best performance and this is time expensive

Zoo of High Level Control tools

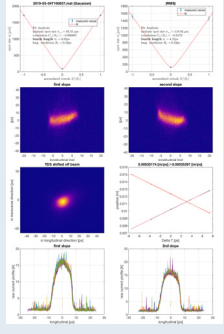
BBA



Beam matching

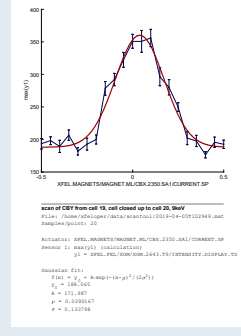


Longitudinal profile measurement



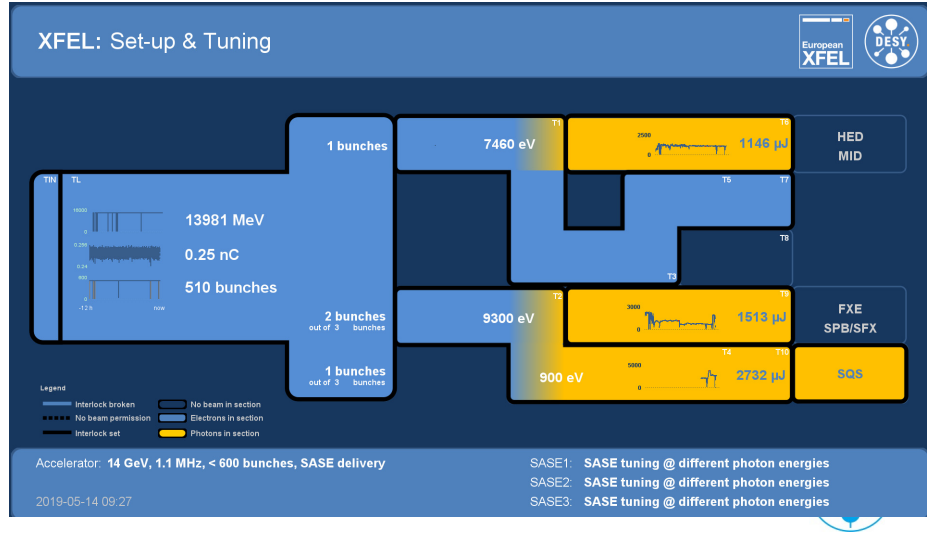
Orbit correction

Scan tool



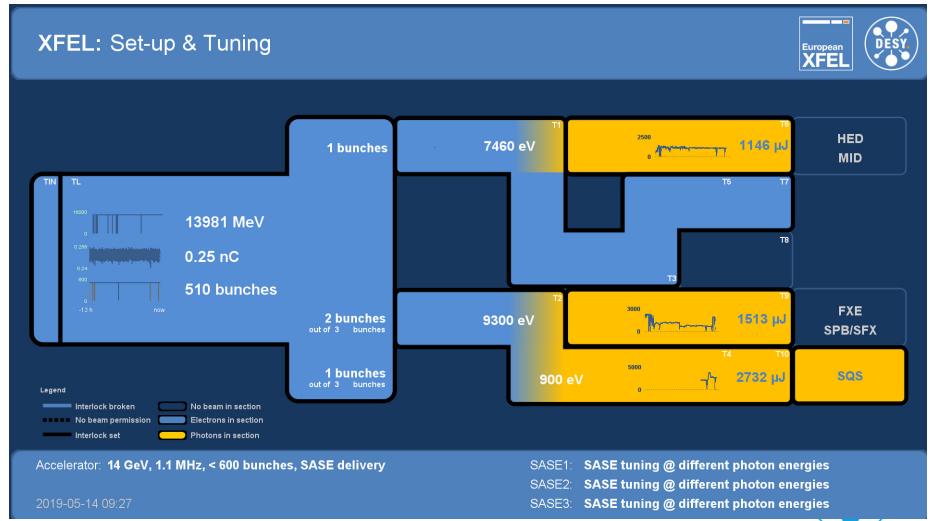
Motivation

- Multi-user operation puts additional pressure on the photon beam quality and the availability of the machine for users



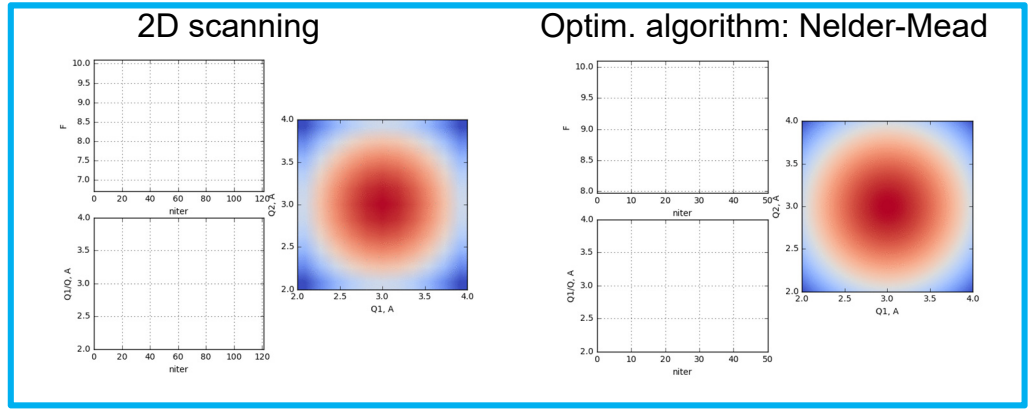
Motivation

- Multi-user operation puts additional pressure on the photon beam quality and the availability of the machine for users
- More automation of the tuning procedures is needed
- OCELOT Optimizer & Adaptive feedback
- OCELOT multiphysics simulation toolkit
  - Includes: beam dynamics, photon field simulation, online beam control modules
  - everything in python
  - open source
  - https://github.com/ocelot-collab/



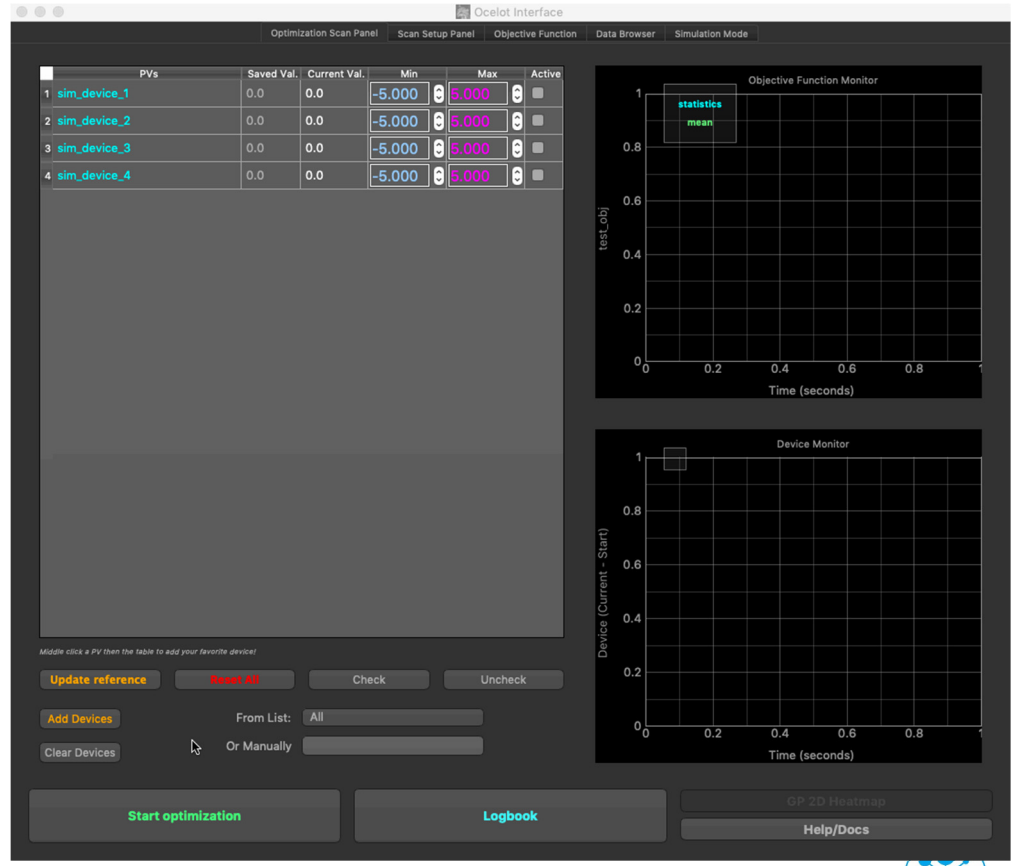
OCELOT Optimizer

- Optimization algorithms are faster than scanning



OCELOT Optimizer

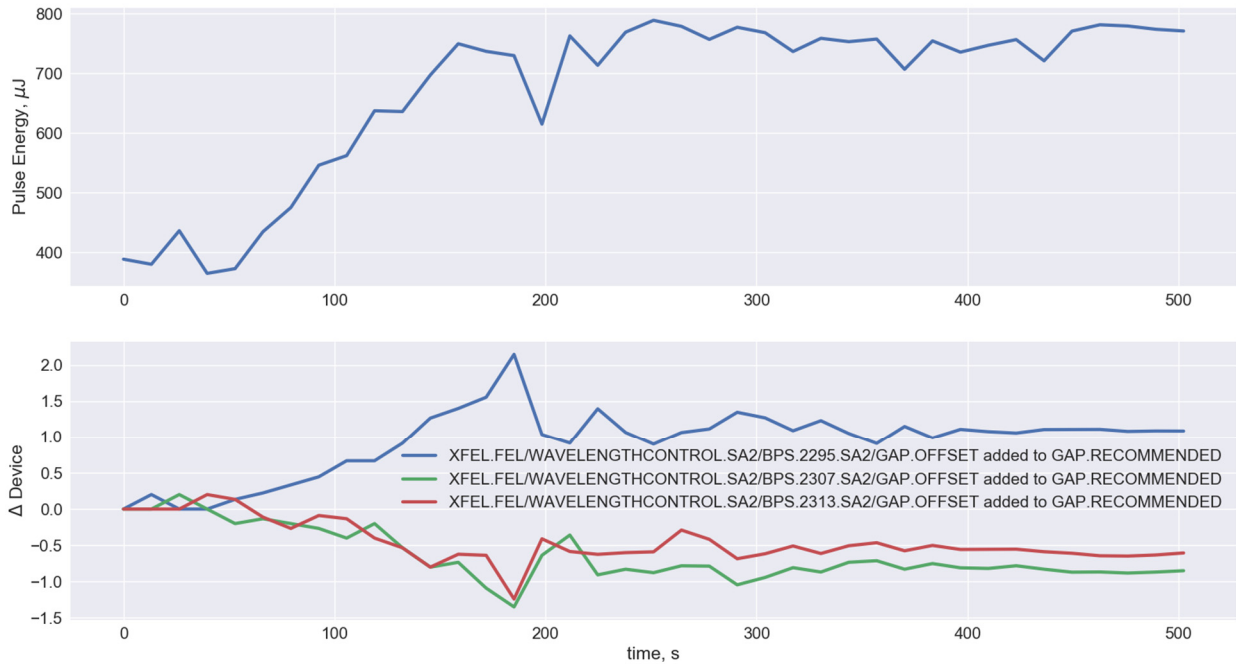
- Optimization algorithms are faster than scanning
- OCELOT optimizer is a flexible platform for optimization:
  - Interchangeable optimization methods
  - GUI
    - ► Add/select device or group of devices
    - ► Craft/modify target function
  - Infrastructure for testing new methods
  - Save/load configs
  - Logging
- Collaboration DESY, EuXFEL, SLAC



I. Agapov et al, arXiv:1704.02335
S. Tomin et al, https://doi.org/10.18429/JACoW-IPAC2017-WEPAB031
M.W. McIntire et al, DOI:10.18429/JACoW-IPAC2016-WEPOW055

OCELOT Optimizer: Use cases

- European XFEL
  - FEL pulse energy maximization:
    - ▶ Orbit inside an undulator
    - ▶ Phase-shifters
    - ▶ Orbit in injector
    - ▶ Matching quads
    - ▶ RF settings



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    - ▶ Orbit inside an undulator
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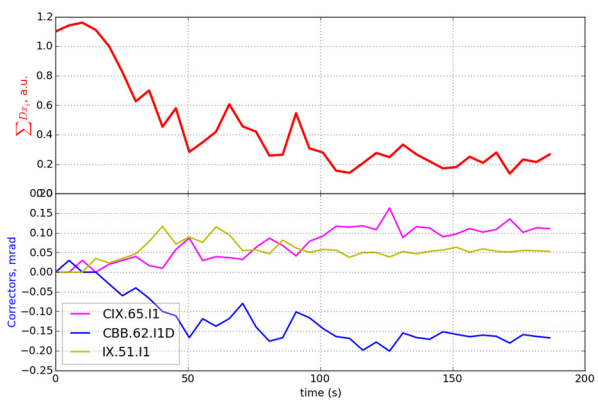
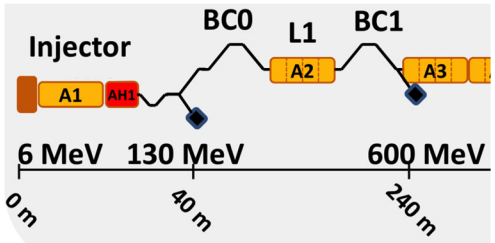
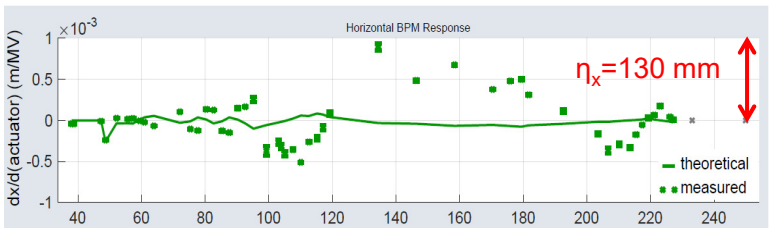
    - ▶ Matching quads
    - ▶ RF settings
  - Local dispersion correction in injector

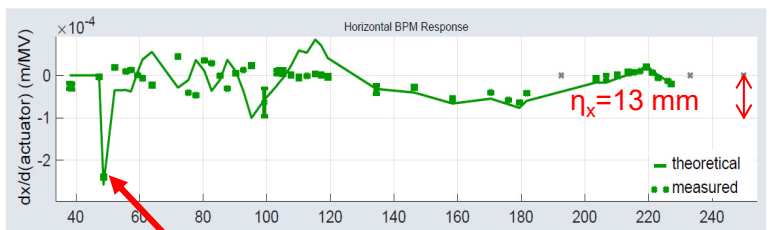




Before correction

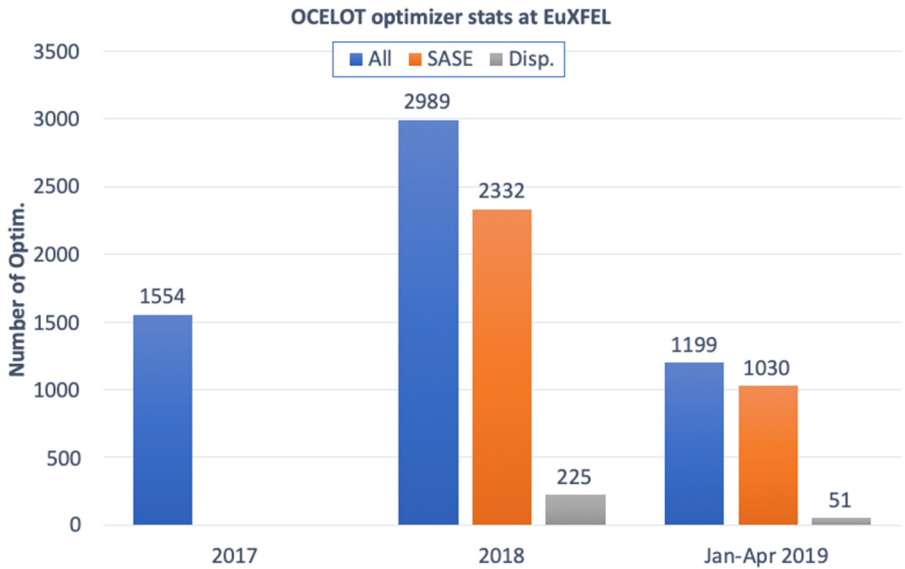


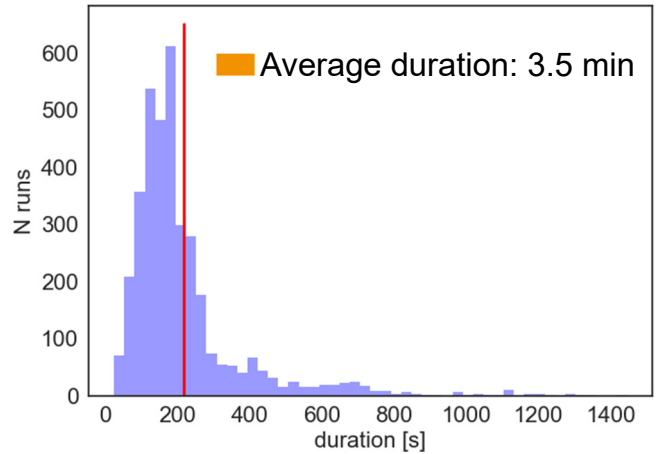
After correction

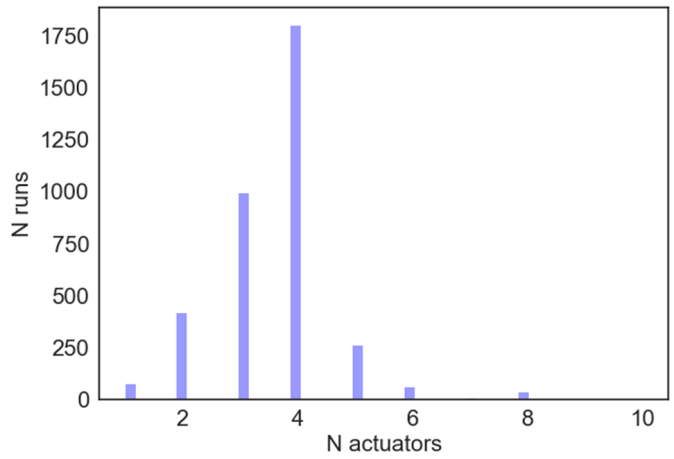


Laser Heater chicane

OCELOT Optimizer: Statistics







Most of optimizations are used 4 devices and average time duration of a single optimization is 3.5 minutes

OCELOT Optimizer: Statistics

Percentage of “effective” optimization runs

Period	$\frac{\Delta S}{S_0} > 10\%$
Dispersion local minimization	
Statistics for 16 months	62%
FEL pulse energy maximization	
Statistics for 16 months	18%

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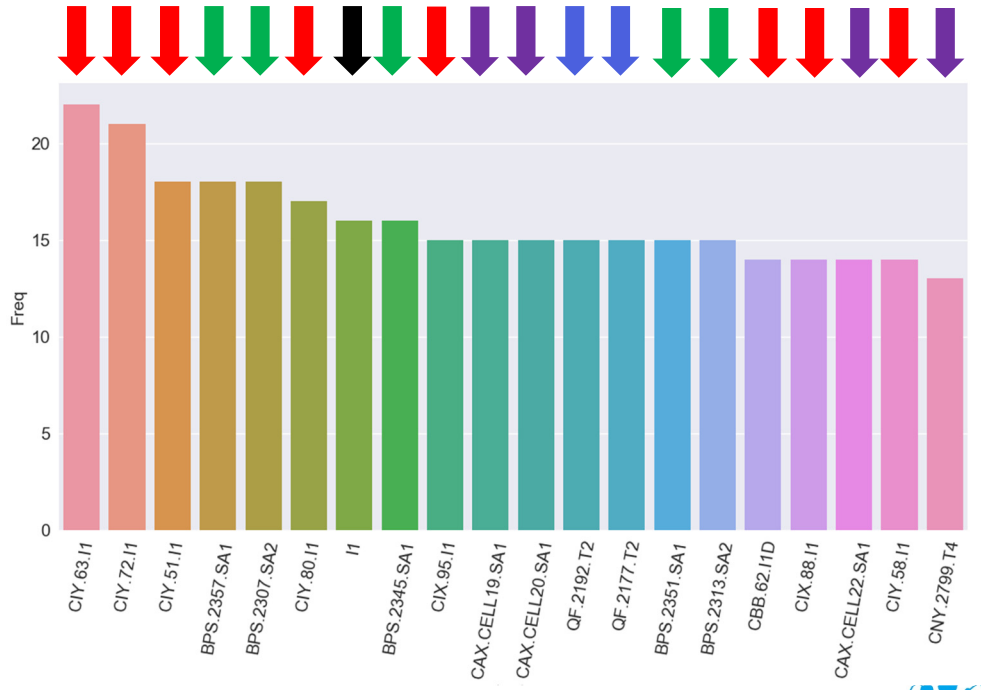
- Number of unique devices used for optimization
  - FEL optimization: 446 unique devices
  - Dispersion: 28
- The less constrains -> more flexibility -> less efficiency

OCELOT Optimizer: FEL optimization. Identifying stricter constraints

- Chart of devices are used in “effective” optimization runs
  - Injector orbit tuning
  - Undulator phase shifters
  - Orbit in undulator
  - Injector energy chirp
  - Undulator matching quads
- We plan to update the recommended configurations for operators
- Machine status data will be included in the log for future use to define the model for FEL optimization



Adaptive Feedback

- The "Adaptive Feedback" is a statistical optimizer exploiting the orbit jitter and its correlation with a fast FEL intensity signal (shot-to-shot resolution) to optimize the undulator launch orbit

G. Gaio, M. Lonza, Automatic FEL Optimization at FERMI, Proc. of ICALEPCS2015

Adaptive Feedback

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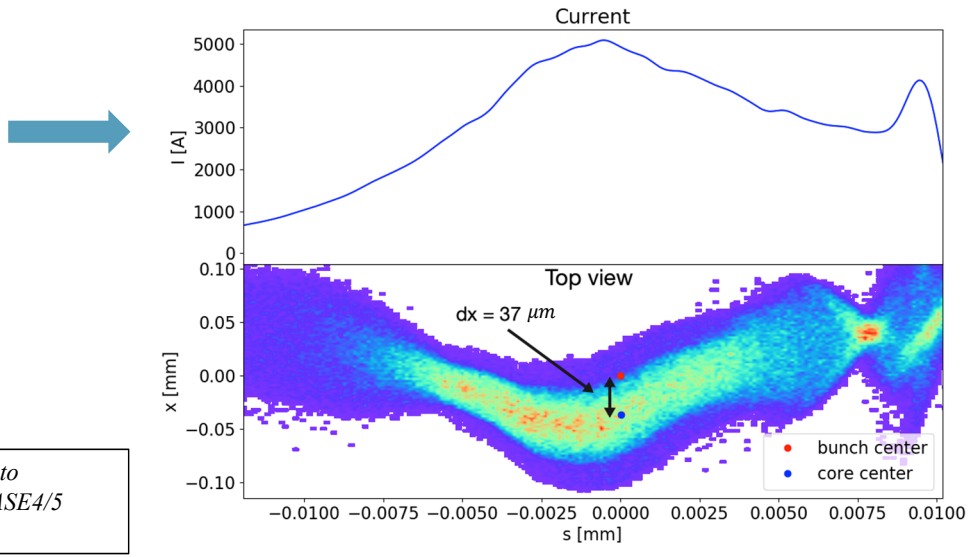
- Correcting the orbit to zero BPM positions does not always mean a straight line for lasing slice

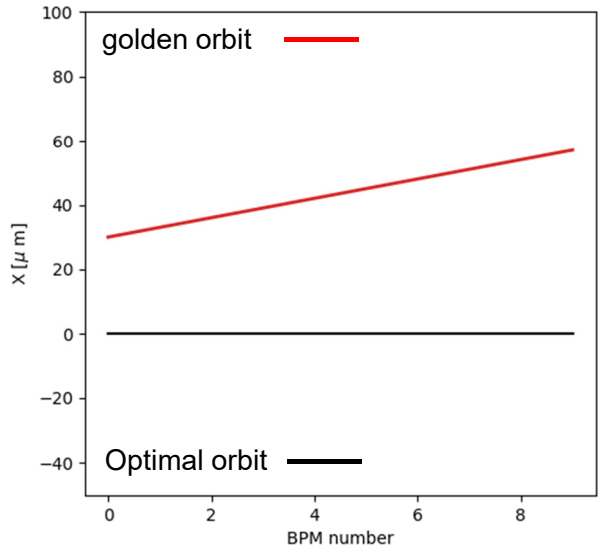
Current and top view of the electron beam (250 pC, 17.5 GeV) in front of SASE2 undulator. Simulation result



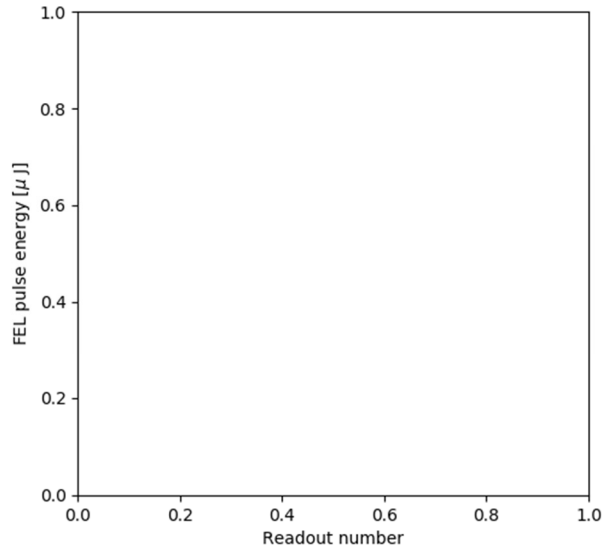
M. Dohlus, S. Tomin, and I.Zagorodnov, "Beam Dynamics at the European XFEL up to SASE4/5", Workshop „Shaping the Future of the European XFEL: Options for the SASE4/5 Tunnels"

Adaptive Feedback: how it works

Horizontal orbit in undulator



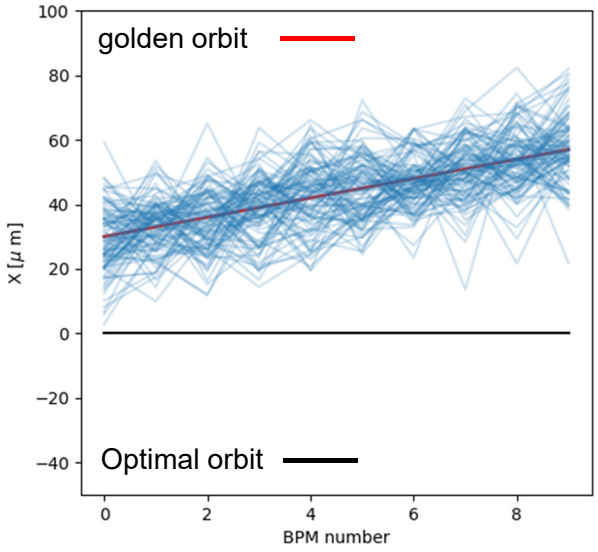
FEL pulse energy



Iteration #1

Adaptive Feedback: how it works

Horizontal orbit in undulator



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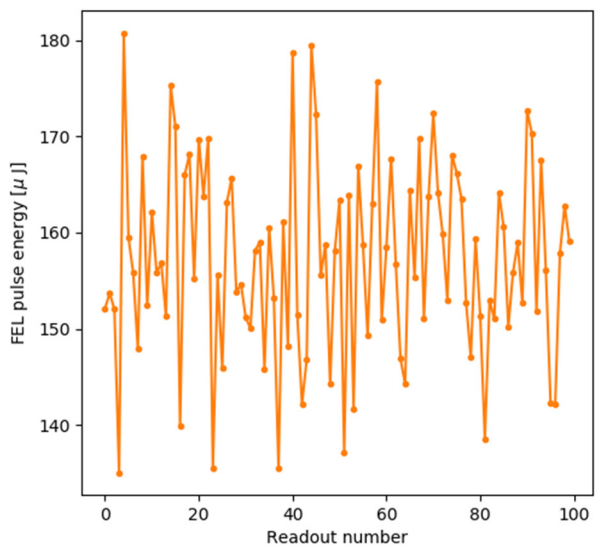

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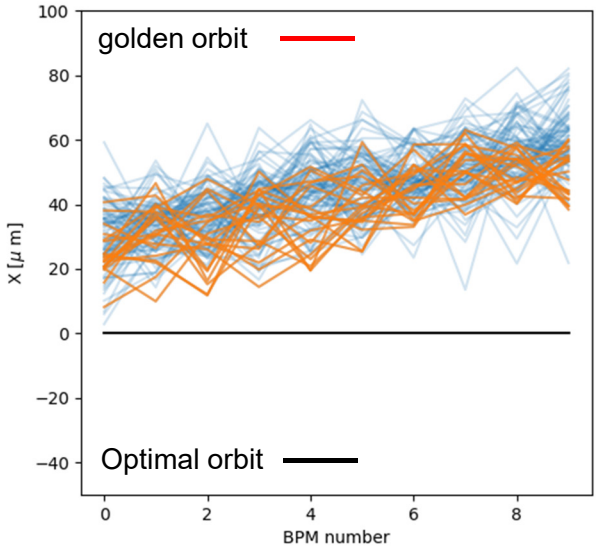

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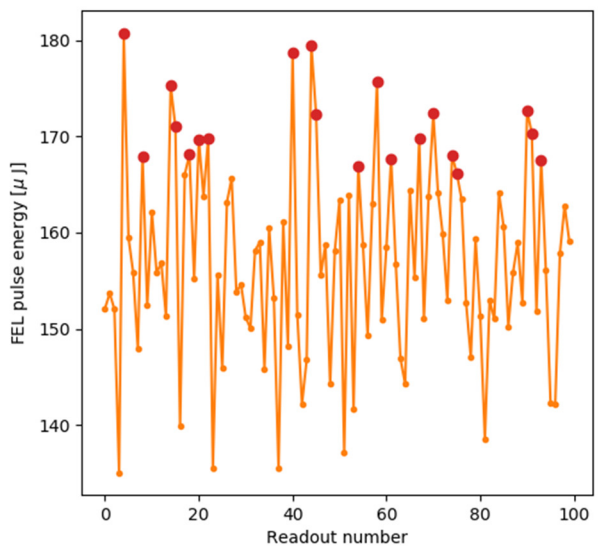

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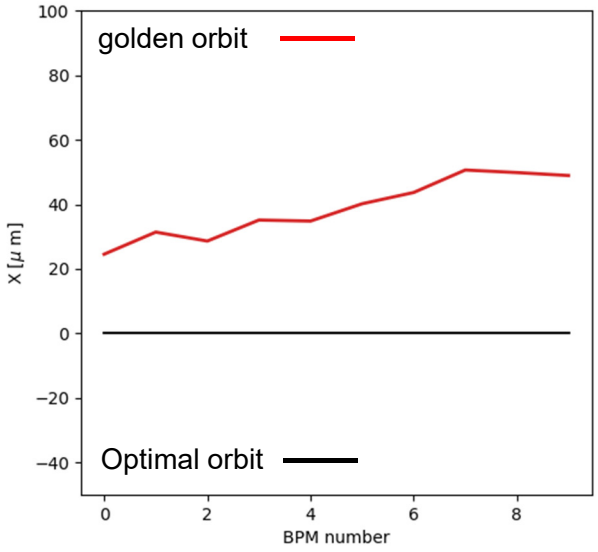

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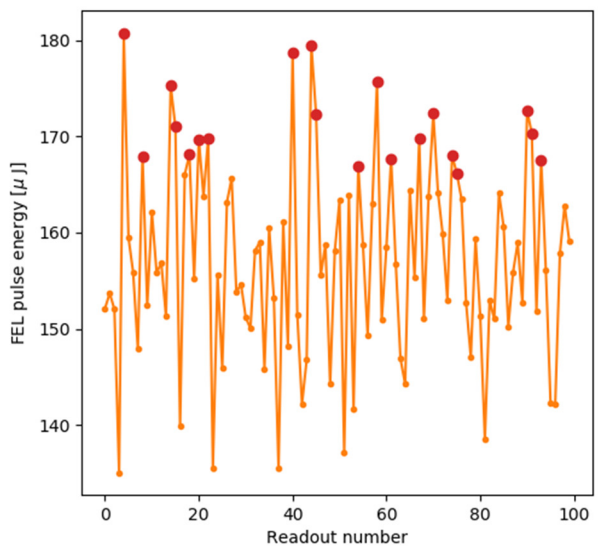

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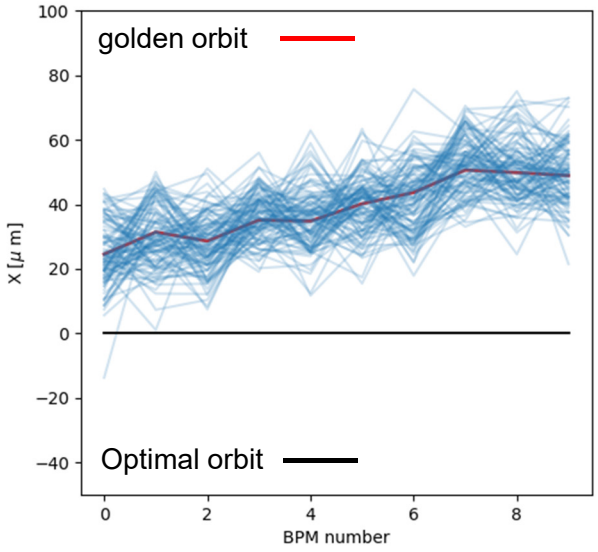
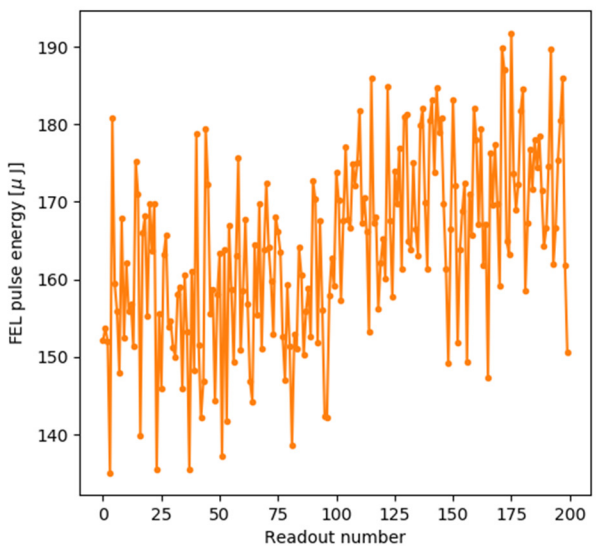


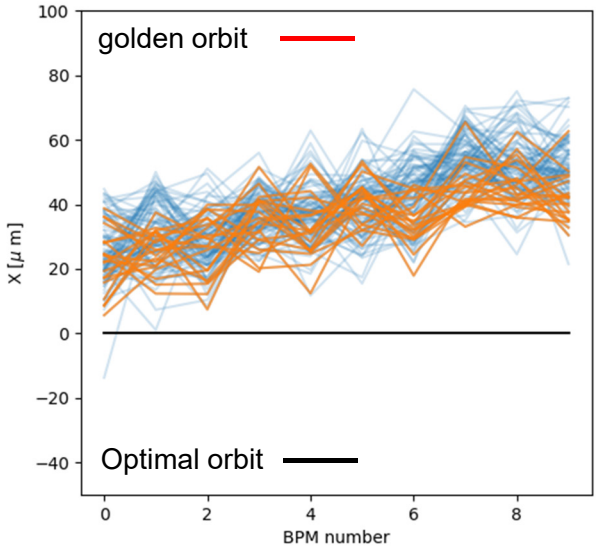
FEL pulse energy



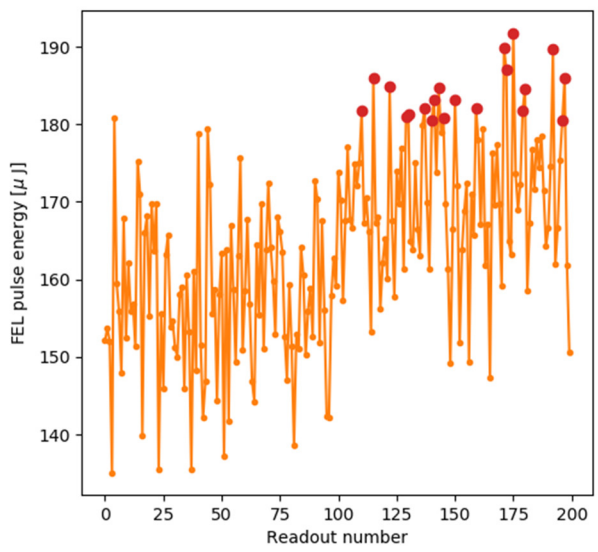
Iteration #2

Adaptive Feedback: how it works

Horizontal orbit in undulator



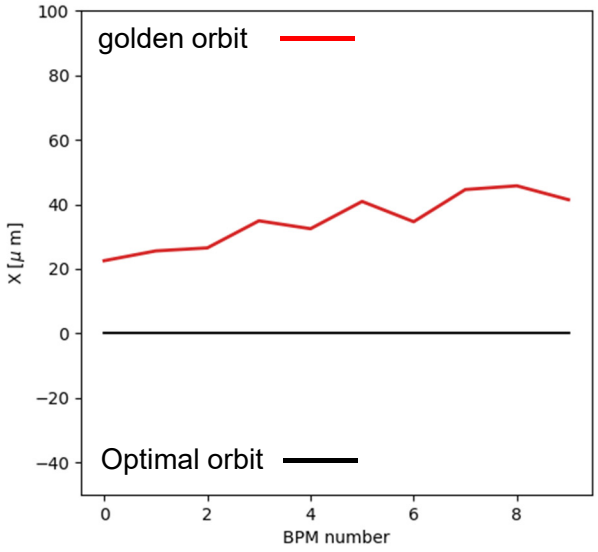
FEL pulse energy



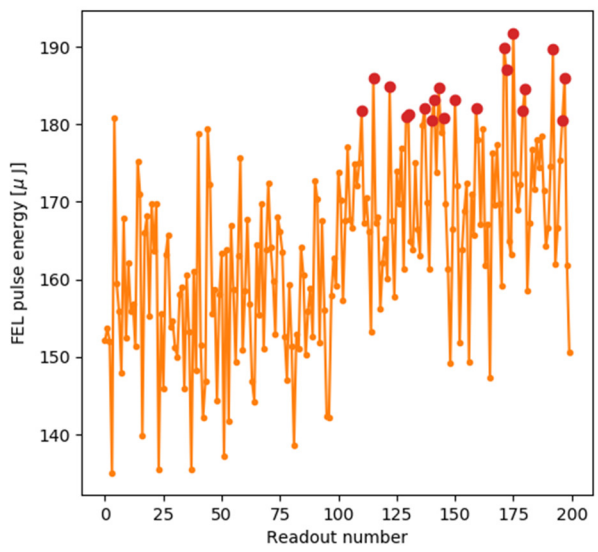
Iteration #2

Adaptive Feedback: how it works

Horizontal orbit in undulator



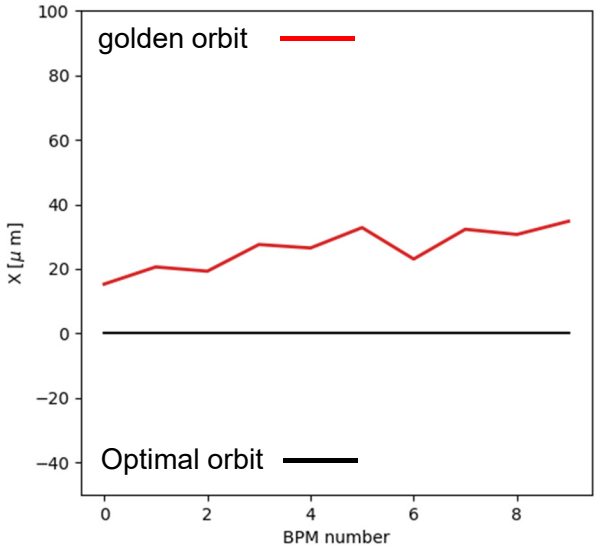
FEL pulse energy



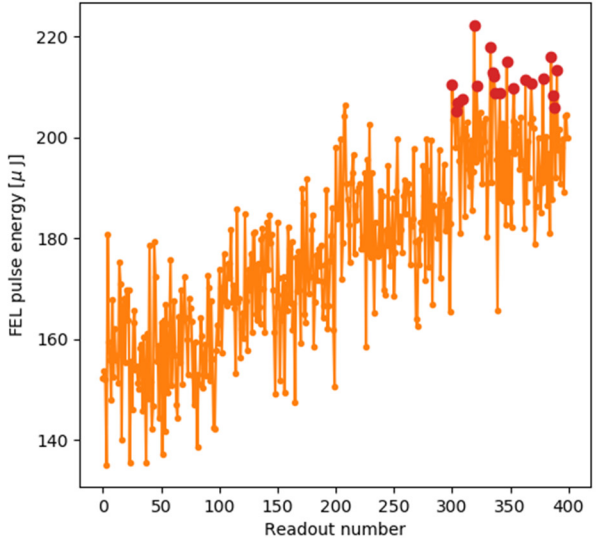
Iteration #2

Adaptive Feedback: how it works

Horizontal orbit in undulator



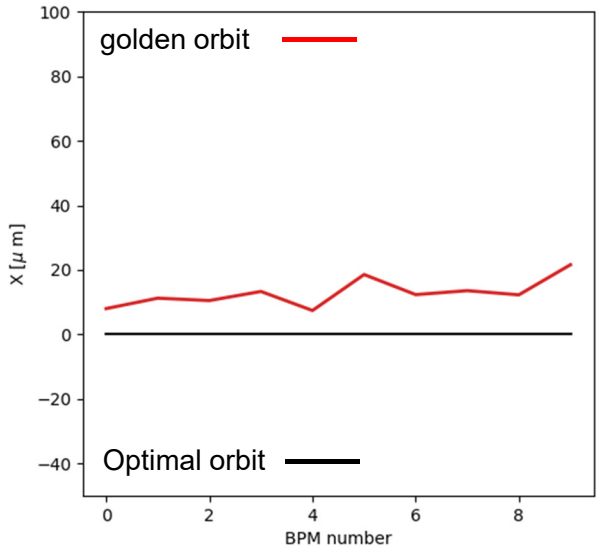
FEL pulse energy



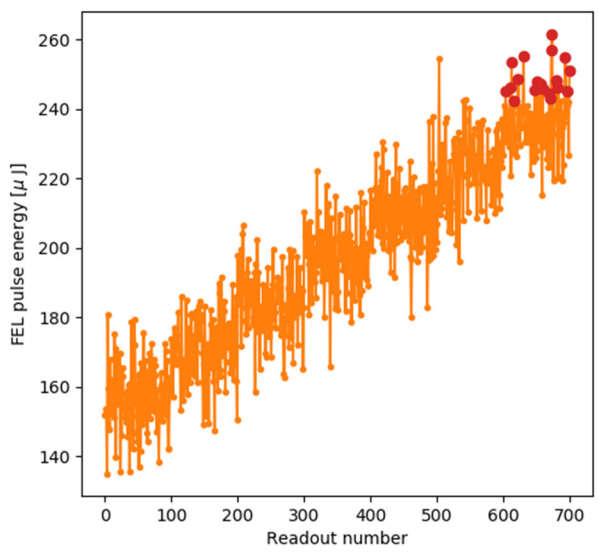
Iteration #4

Adaptive Feedback: how it works

Horizontal orbit in undulator



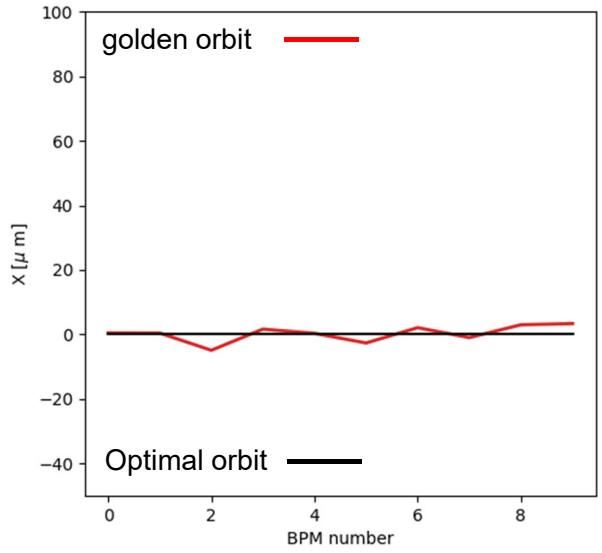
FEL pulse energy



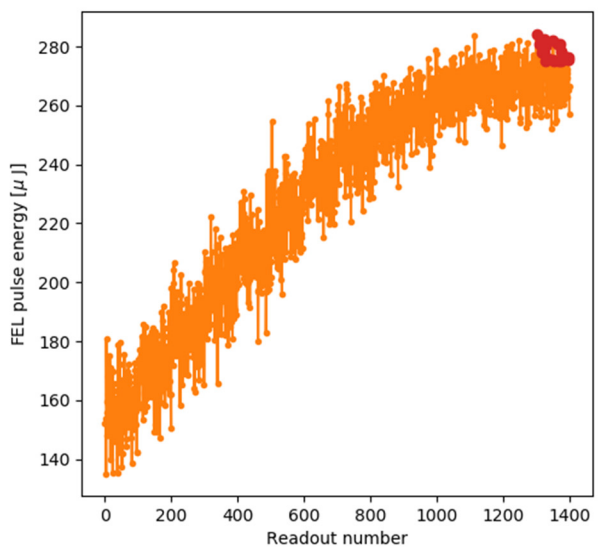
Iteration #7

Adaptive Feedback: how it works

Horizontal orbit in undulator



FEL pulse energy



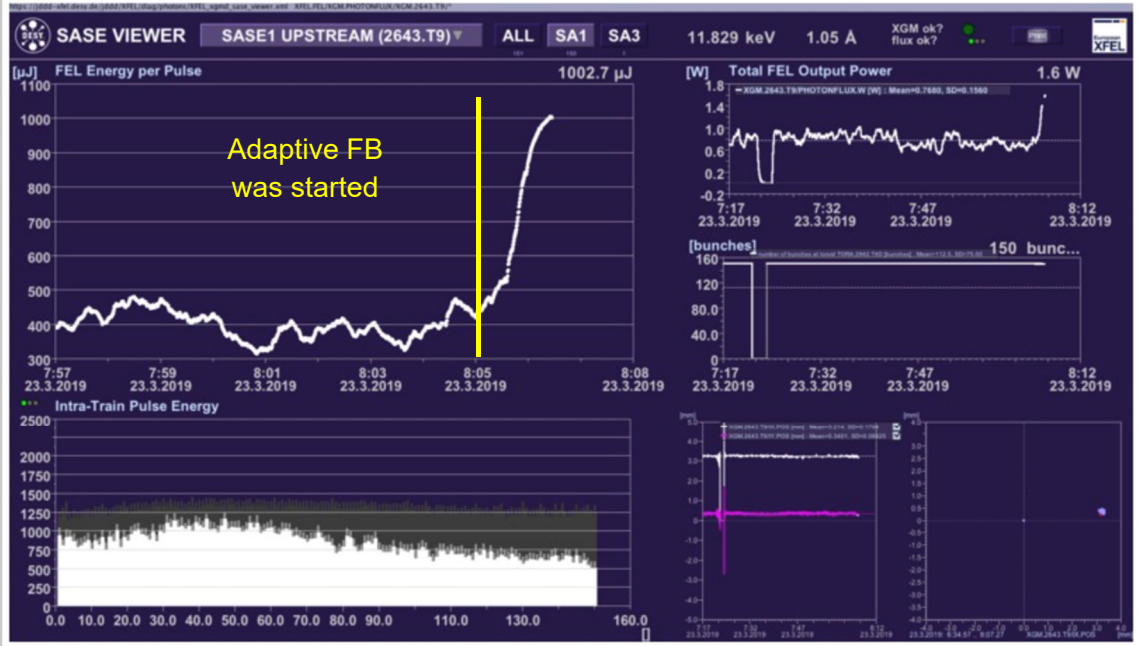
Iteration #14

Adaptive Feedback

Logbook entry: /XFELelog/data/2019/12/23.03_M

23.03.2019 08:06 **XFEL** mscholz, TIS, Artem **XFEL_xgmd_sase_viewer.xml**

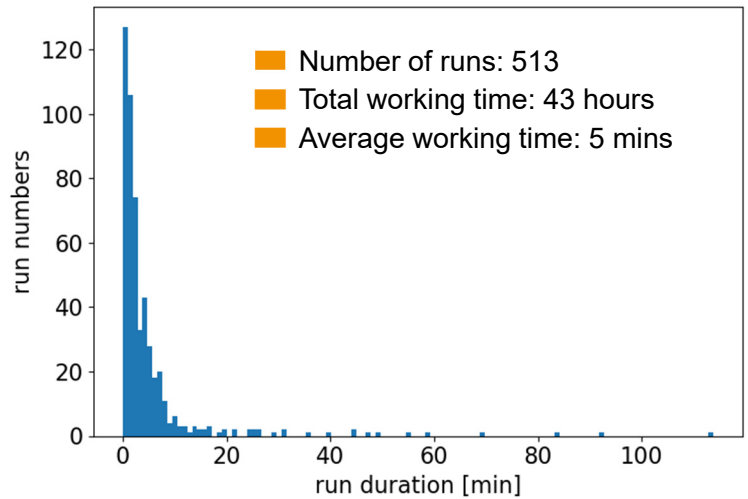
SASE1 signal could be doubles with only starting the **adaptive** FB



Adaptive Feedback statistics

- Adaptive Feedback has become one of the main tools for SASE tuning
- In some cases the adaptive feedback is used as an orbit feedback
- The soft X-Ray FEL pulse energy signal is not sensitive to the orbit jitter in the SASE3 undulator.
  - artificially induced orbit changes have to be used to catch correlations

Statistic of the Adaptive Feedback runs from March 11 to April 7, 2019



Conclusion & outlook

- Automated optimization is a part of the daily European XFEL operation
- The OCELOT Optimizer is efficient compared to manual tuning by the operators
- Analysis of the optimization statistics revealed that two problems must be solved to increase the effectiveness of FEL optimization runs
  - we need to know what to tune in a particular machine state
  - the optimizer hyperparameters should also be adapted to the particular machine state
- The Adaptive Feedback is very effective tool for launch orbit optimization

…so, thanks to all the people who contributed to this work (accelerator team, fel colleagues etc)

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…and thank you for your attention!