Optimizing performance of Apple-X

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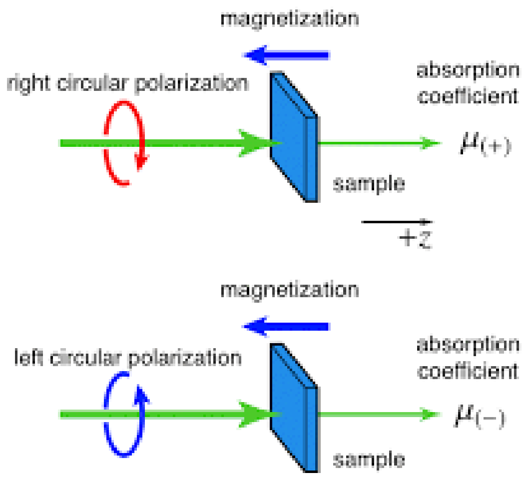
EuXFEL operator training, Hamburg, 18.11.2024

Typical user experiment

- X-ray magnetic circular dichroism (XMCD) in some metals (usually Fe, Co, Ni, …), possibly pump-probe using optical laser;
- Difference in absorbtion for left/right circular polarization is measured;
- The most important property is **polarization purity** which is defined by the **contrast** (pulse energy ratio when Apple-X is on/off resonance);
- Typical numbers: 1 mJ on-resonance, 20 uJ off-resonance (i.e. linearly polarized light coming from SASE3), the contrast is 50.
- High pulse energy might not be required for these experiments but could be important for other experiments.



X-ray magnetic circular dichroism (XMCD)

$\Delta\mu = \mu_{(+)} - \mu_{(-)}$

Optimization goals

- Contrast as high as possible, i.e. pulse energy from SASE3 must be minimized;
- Pulse energy from Apple-X as high as possible;
- Good transverse shape and pointing of the photon beam.

We do not consider short pulses here.

The method: reverse tapering of SASE3

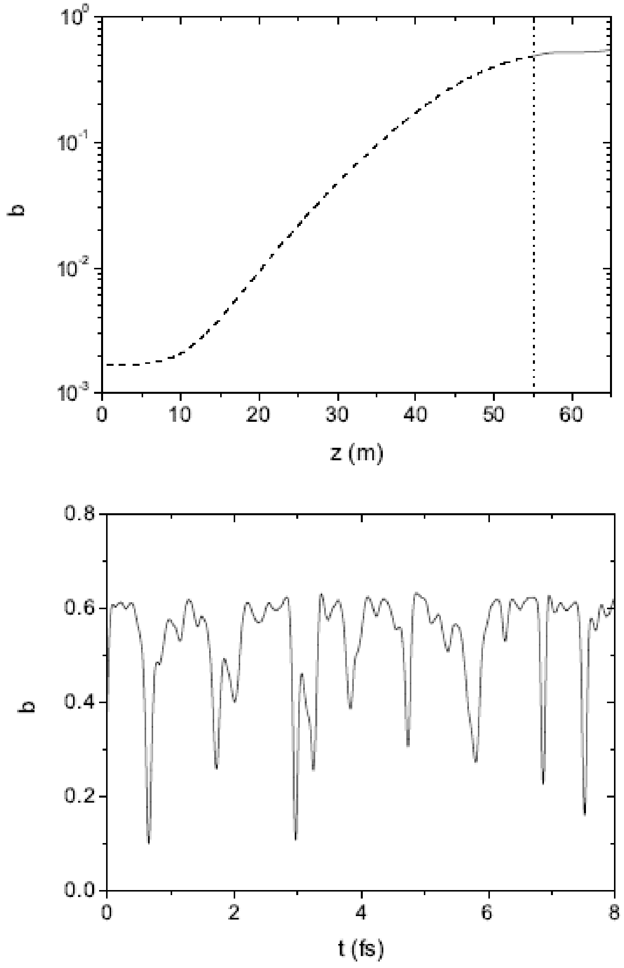
reverse-tapered planar undulator (saturation)

helical afterburner

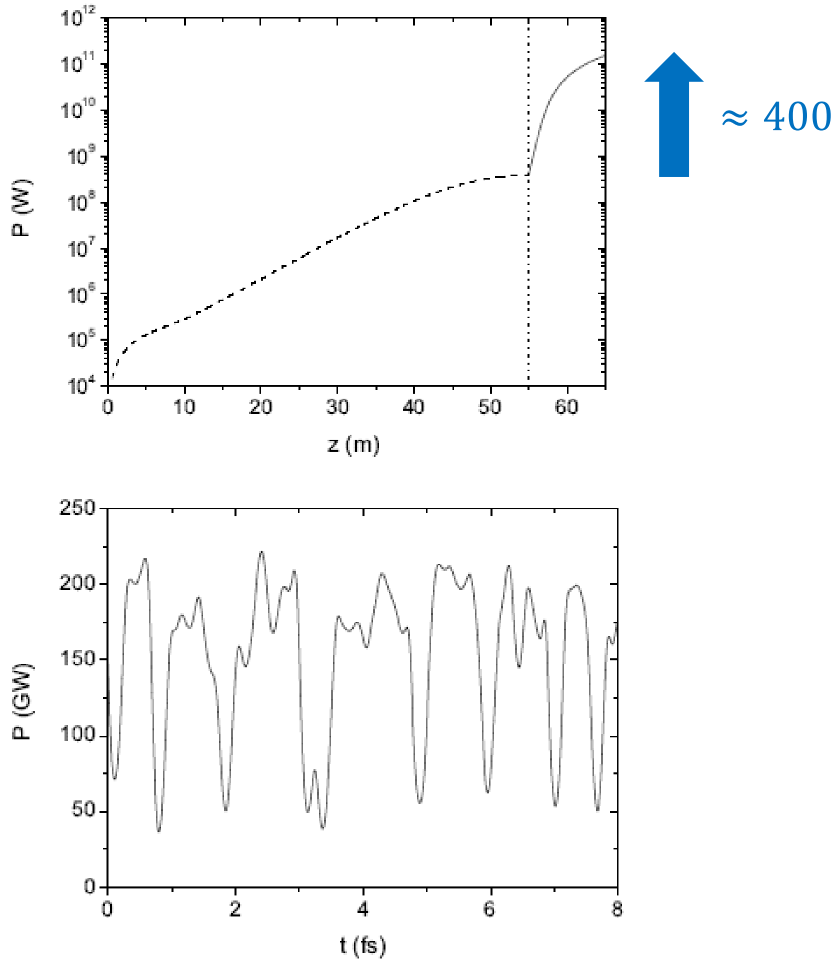
- Fully microbunched electron beam but strongly suppressed radiation power at the exit of reverse-tapered planar undulator
- The beam radiates at full power in the helical afterburner tuned to the resonance

E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 110702(2013)16

SASE3 simulations (2013)



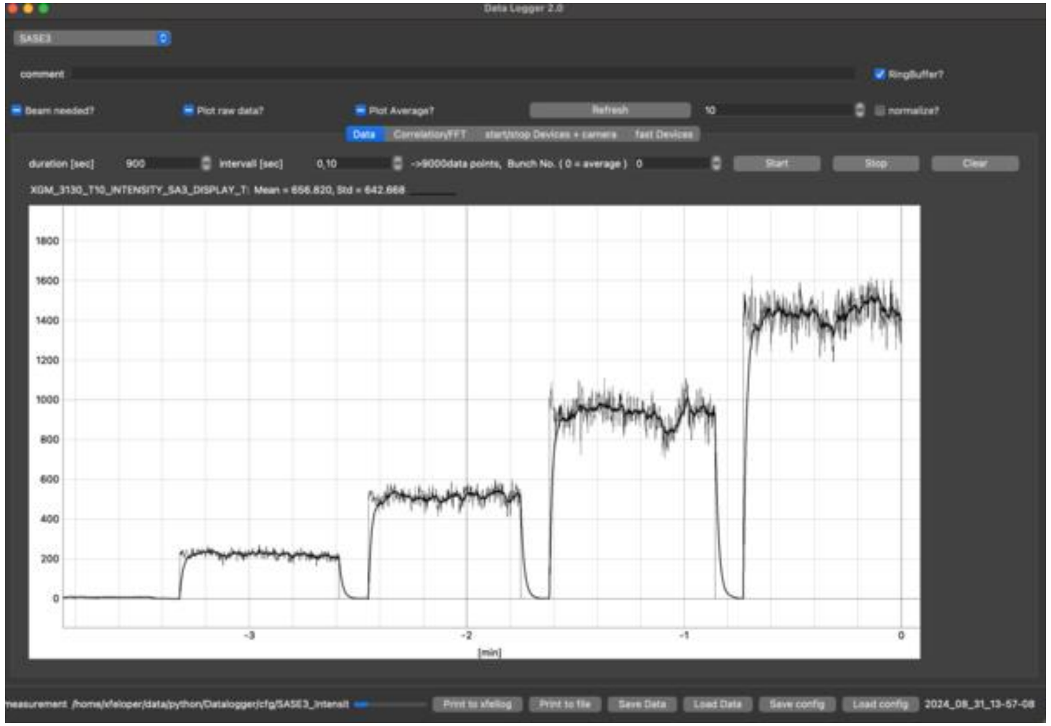
bunching

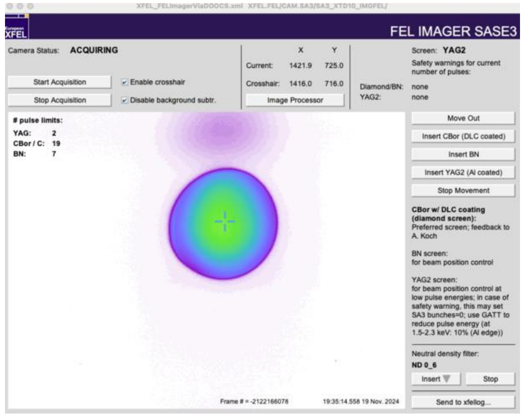


power

FEL commissioning of APPLE-X

- Number of segments and reverse taper strength are close to simulations from 2013;
- Photon energy was usually 1 keV, pulse energy 1 – 1.5 mJ and the contrast up to 90;
- Different polarization states tested.





Tuning iterations

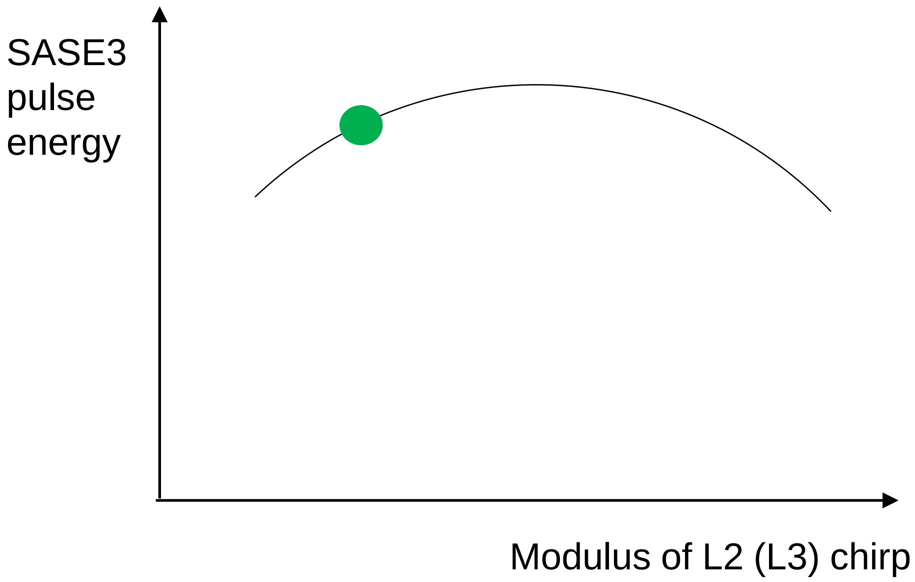
- **Coarse tuning of SASE3**; Apple-X in “no light” state or far from resonance. The main goal is to establish proper suppression of Sa3 intensity while hoping for bunching preservation;
- **Coarse tuning of Apple-X**: optimize orbit and K-value;
- **Fine tuning of SASE3**: optimize reverse taper strength and number of segments plus additional tricks;
- **Fine tuning of Apple-X:** further improve orbit, check phase shifters (usually ok), try linear or quadratic taper (positive) …

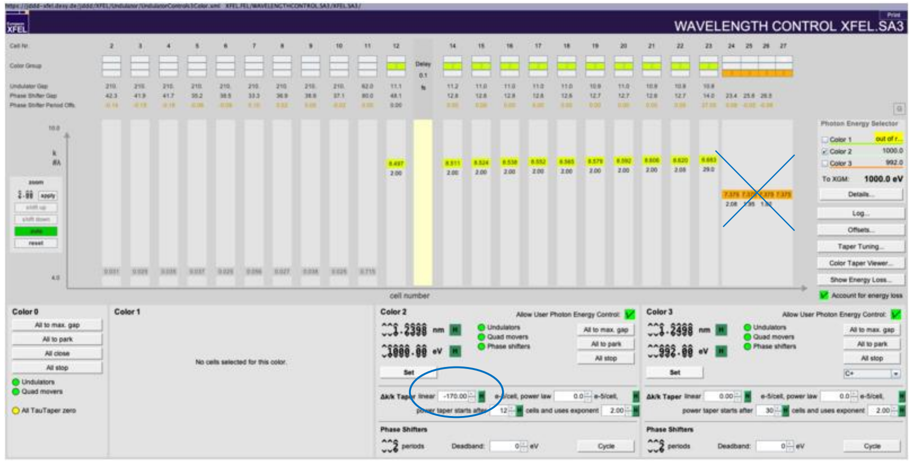
Possible shortcut

Restore settings for SASE3 and Apple-X from a recent good regime using E-photon energy change tool (incl. quad movers); then do fine tuning.

Coarse tuning of SASE3

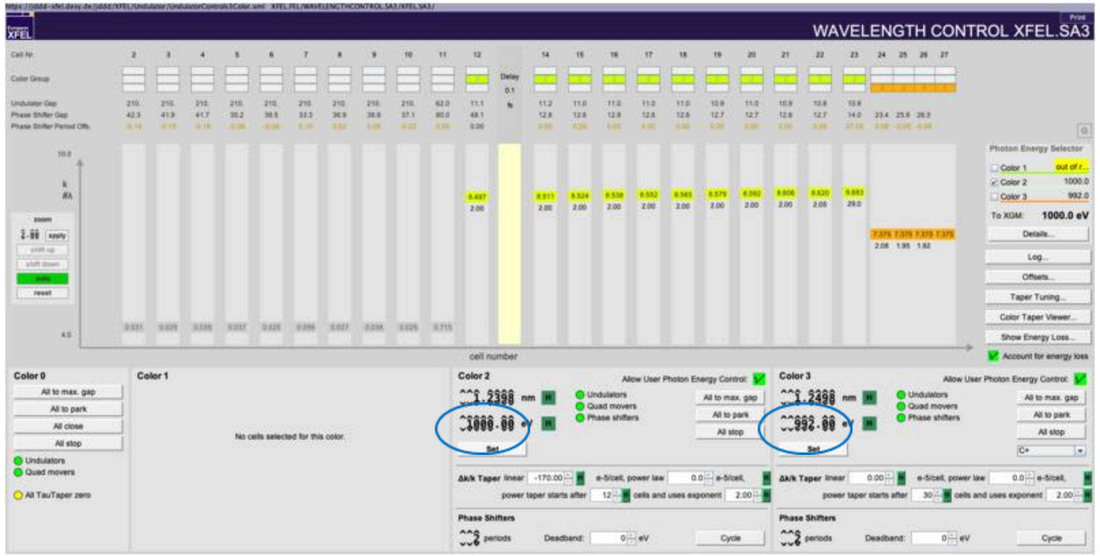
- Start with normal SASE, untapered undulator; use 10 last segments; Apple-X off-resonance;
- When not in interleaved mode: L2 or L3 chirp should be on the left from the maximum (compress weaker with ~ 10% reduction of intensity);
- Vary number of segments to be roughly at saturation; aim at ~ 2 mJ (typically 9 – 12 segments);
- Make sure that the beam is not far from the center on FEL imager;
- Apply reverse linear taper (typically between -150 and -200): pulse energy should be ~ a couple of tens uJ (use fast XGM signal even if it is not accurate at this level).

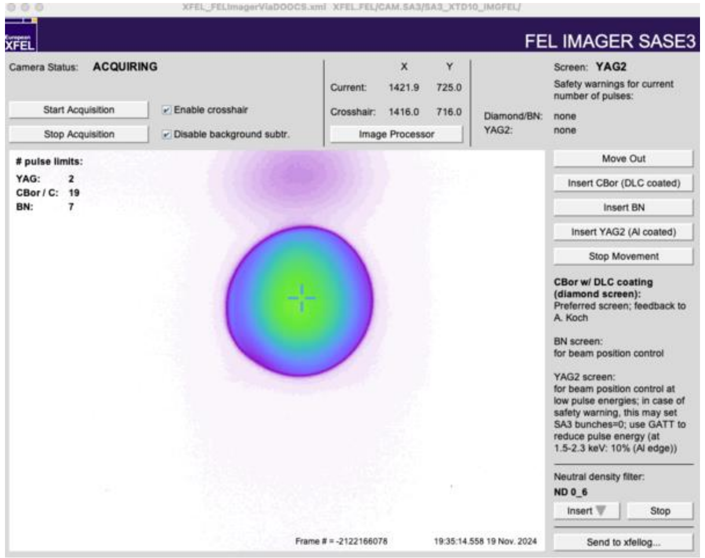




Coarse tuning of Apple-X

- Close all 4 segments, go to C+ (or C-) mode and optimize photon energy (the optimal value is usually lower than Sa3 by roughly 10 eV); few eV offset can spoil beam shape;
- Close Apple-X segments one by one, optimize steerers in front; also quad movers in front of the 1st and the 3rd segments;
- Try not only to improve pulse energy but also watch FEL imager, avoid bad shapes.





Fine tuning of SASE3

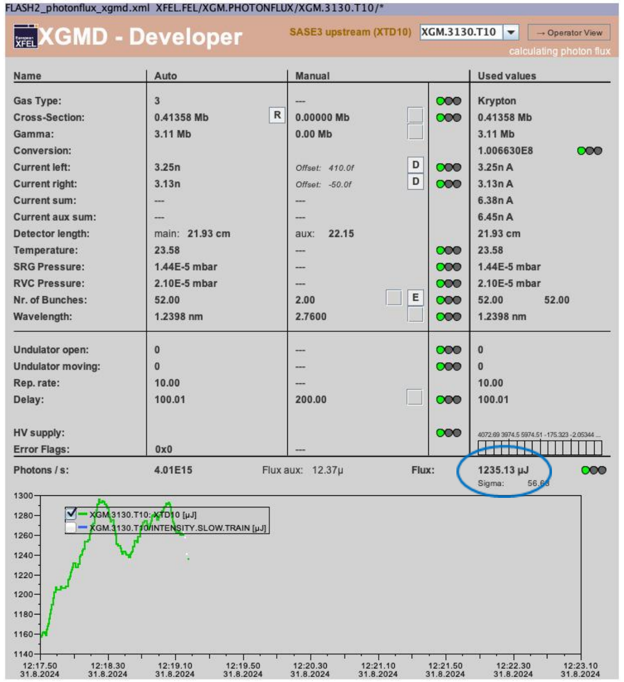
- Try to optimize both the contrast and the pulse energy from Apple-X; for this move Apple-X on/off resonance after some changes in SASE3;
- Vary two main parameters: number of segments and linear taper strength;
- As a refinement, play with phase shifter in front of the last segment #23, and with K-offset of this segment;
- …

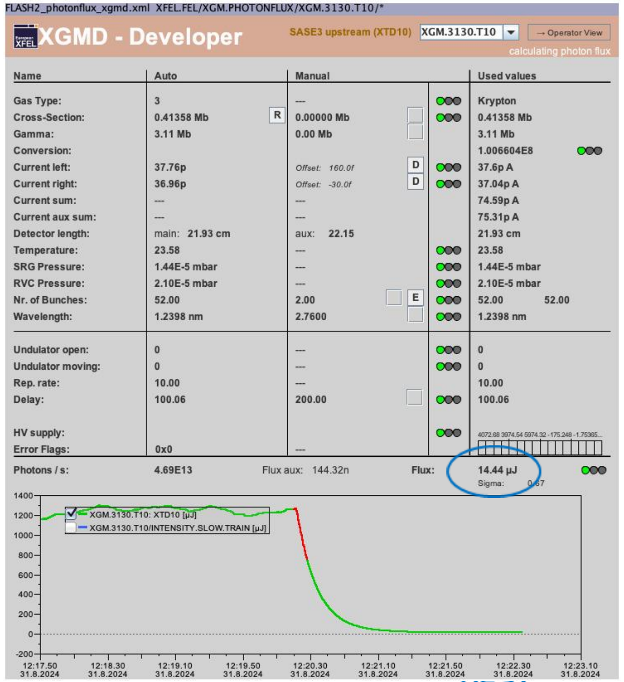
Fine tuning of Apple-X

- Check phase shifters in Apple-X (usually ok at nominal settings though);
- Try linear or quadratic taper (positive);
- Do fine adjustment of orbit and photon energy;
- …

Contrast measurements

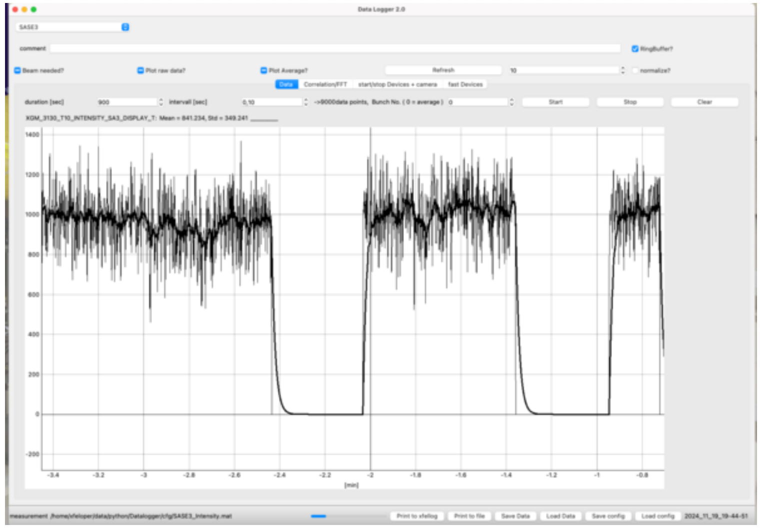
- When Apple-X is off resonance, pulse energy from Sa3 is at 10-20 uJ level; fast signal of the XGM is very inaccurate;
- Increase number of bunches to several tens, use slow (ion signal);
- For calculation of pulse energy it uses sum of number of bunches in Sa1 and Sa3; for the contrast calculation this does not matter but for absolute energies one can correct by the factor (N_sa1+N_sa3)/N_sa3.





Useful remarks

- Photon energy change within a small range (few tens eV) can be simply done by parallel shift of Sa3 and Apple-X;
- Changes ~ 100 eV may require additional tuning (mainly number of Sa3 segments and taper strength), steering to the reference orbit;
- Switching between C+ and C- is quick, same performance;
- Pulse energies for linear polarization are smaller by roughly a factor of two than for circular - no worries, expected from theory;
- …



From C+ to C- and back

Backup slides

Reverse taper in a nutshell

- Reverse taper = increase of K-value along the undulator length (in contrast with reducing it in case of post-saturation taper).
- In case of SASE, reverse taper creates frequency detuning: radiation frequency at a given position in the undulator is blue-shifted w.r.t. resonance frequency for a current K-value.
- This shift is responsible for the effect: bunching is strong at a weak e.m. field.
- In a seeded FEL the blue shift can be created w/o reverse taper, just by K-offset.
- The effect can be easier understood in the steady-state regime: detuning from resonance creates strong disbalance between the three quantities: e.m. field, energy modulation and bunching (backup slides).