



XFEL Operator Training - APPLE-X undulators

Suren Karabekyan, EuXFEL Schenefeld
Evgeny Schneidmiller, DESY Hamburg

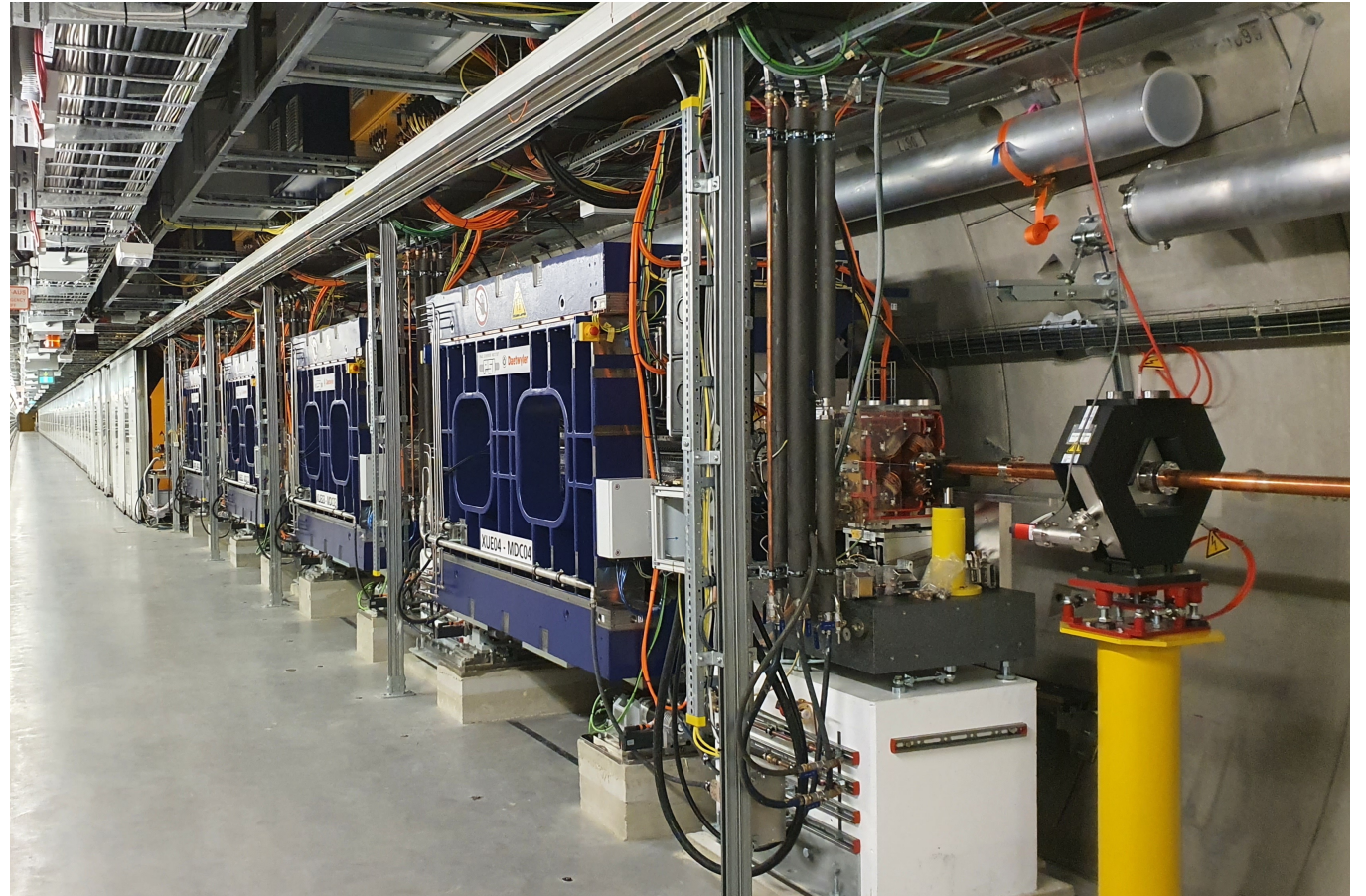
XFEL Operator Training
Nov. 20. 2024

Overview

- Helical afterburner: Concept, implementation
- Design of APPLE-X Helical Undulator
- Polarization modes
- Control panels

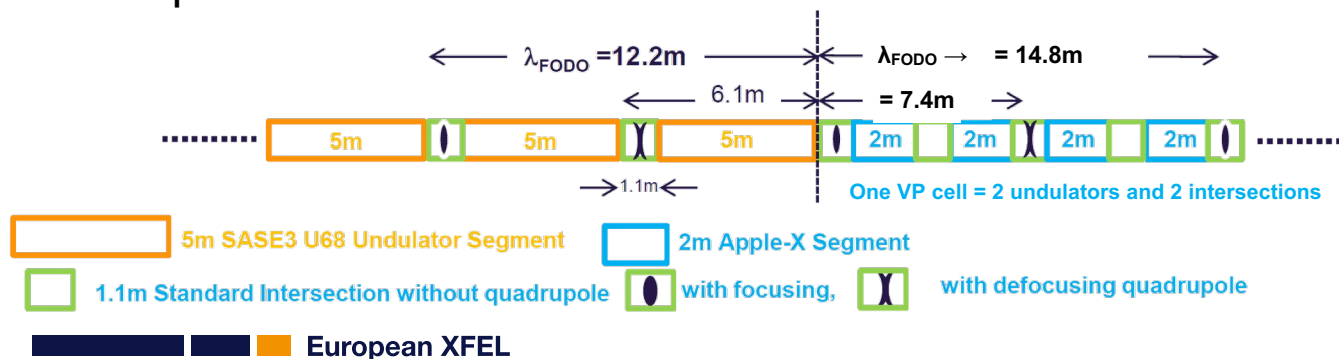
Soft X-ray variable polarization afterburner

- The idea is to use a micro bunched electron beam after a system of planar undulators and direct it into a system of helical undulators tuned to the resonant frequency
- A reverse tapering is used to suppress linearly polarized radiation from the planar undulators and obtain a high degree of circular polarization (*E. A. Schneidmiller and M. V. Yurkov, Phys. Rev. ST+AB 2013, 16: 110702*)

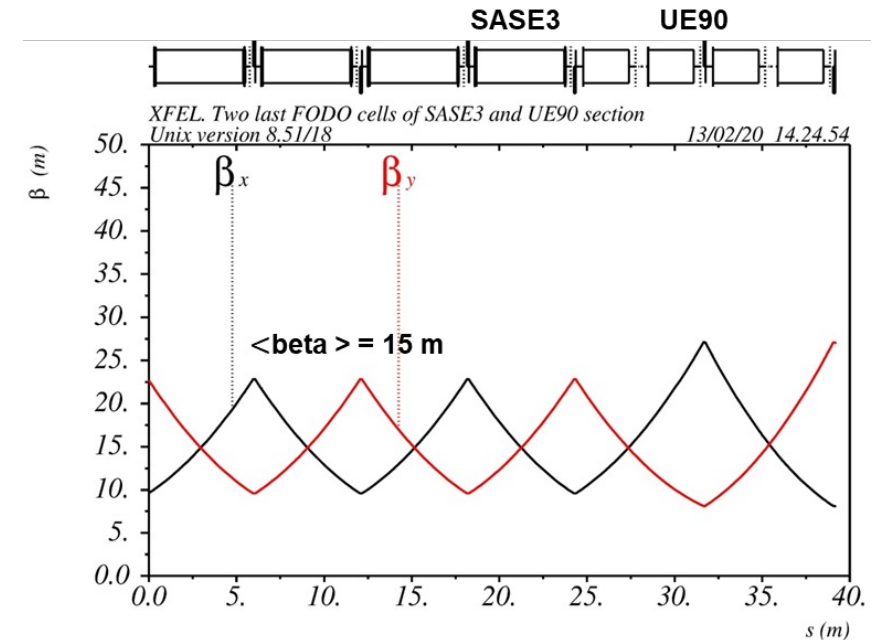


Electron beam optics

- Four APPLE-X undulators are installed directly after the last SASE3 undulator cell
- No matching section in between
- Optics in afterburner section is defined by optics in SASE3 undulator system
- Quadrupoles are installed behind each planar undulator and a pair of Apple-X undulators
- Phase shifters are installed behind every undulator except the last one

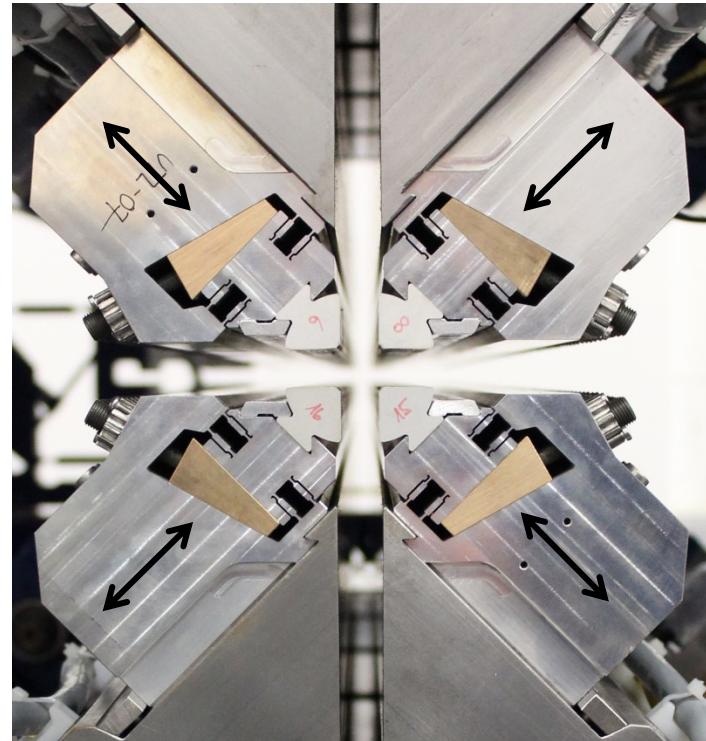
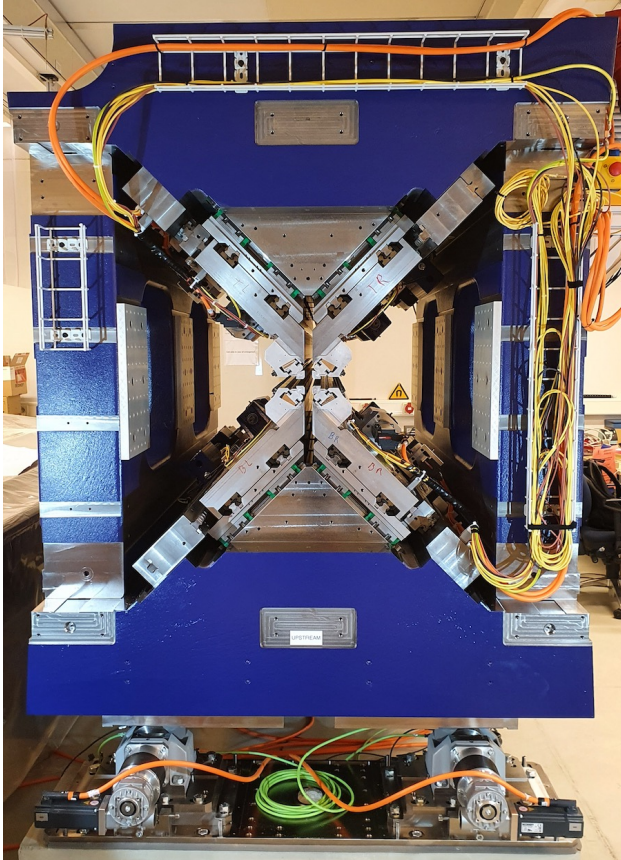


- FODO lattice configuration for afterburner section
 - Space of 2.6 m is reserved for the placement of Apple-X
 - 2 undulators between quadrupoles (QA)
 - 1.1 m long intersection between undulators (either with or without quadrupole)
 - Length of FODO period: $4 \times (1.1 + 2.6) = 14.8\text{ m}$

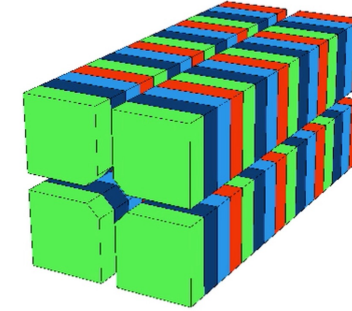


Example for average betatron functions of 15 m in SASE3
 N. Golubeva, W. Decking

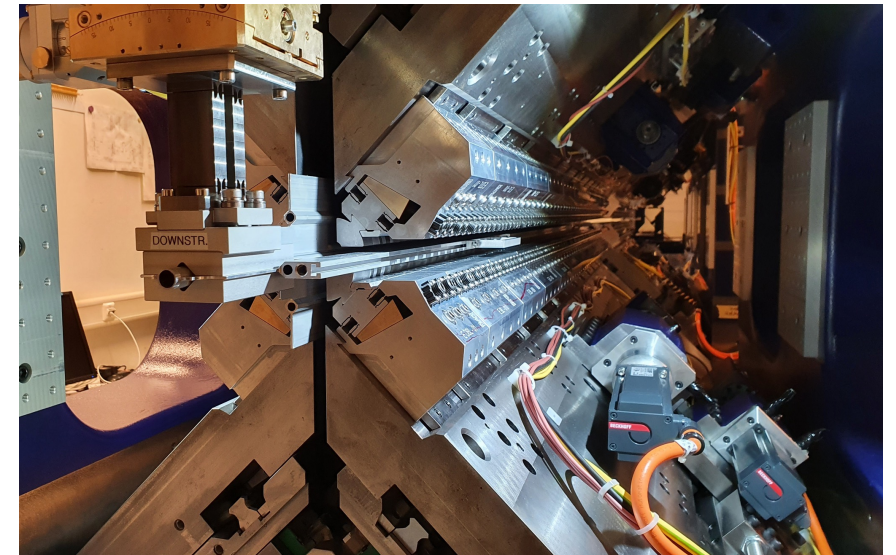
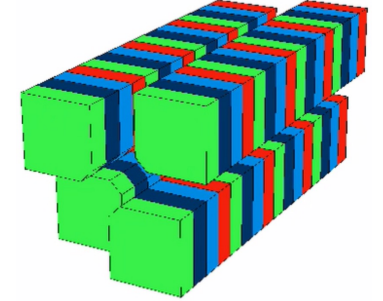
Design of APPLE-X Undulator



Linear Horizontal mode



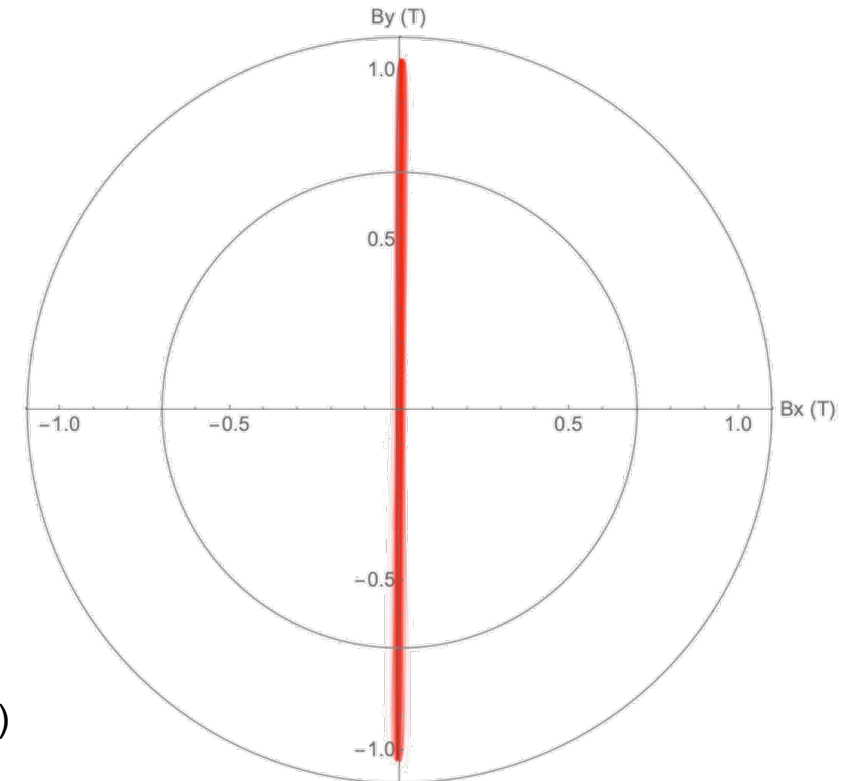
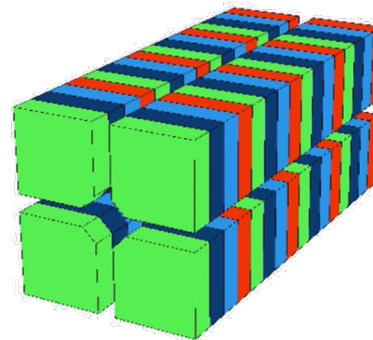
Linear Vertical mode



- APPLE - Advanced Planar Polarized Light Emitter
- APPLE-X – is a „Delta“ type helical undulator, rotated by 45° around the magnetic axis.
- It allows to vary not only the longitudinal but also the radial displacement of all 4 magnetic structures

APPLE-X undulators control – Polarization modes

- No Light mode corresponds to the minimum magnetic field or K value
 - Girder - Radial positions: Top Left (TL) = Top Right (TR) = Bottom Left (BL) = Bottom Right (BR) = 15.8mm
 - Girder Shift positions: TL = TR = 22.5 mm, BL = BR = -22.5 mm
- Mixed/Undefined mode
 - Not all undulators in the selected color are in the same polarization mode
- Linear Horizontal (LH) mode girder position
 - Radial: 6.25mm – 15.8mm
 - Shift
 - ▶ TL: 0 mm
 - ▶ TR: 0 mm
 - ▶ BL: 0 mm
 - ▶ BR: 0 mm



Visualization by M. Calvi (PSI)

Polarization mode - Circular Clockwise (C+), Circular Anti-clockwise (C-)

■ C+ and C- modes are from the experiments point of view (from downstream to upstream)

■ Circular mode girder position

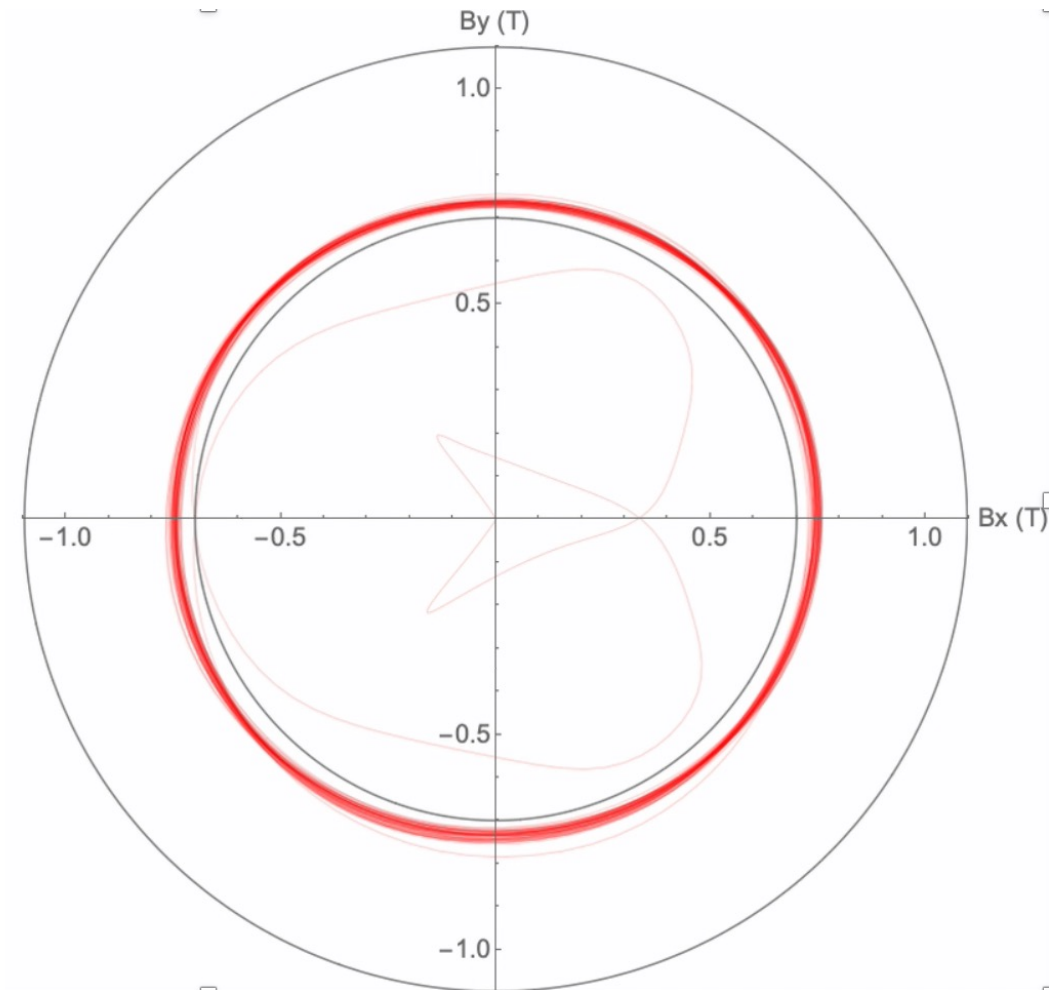
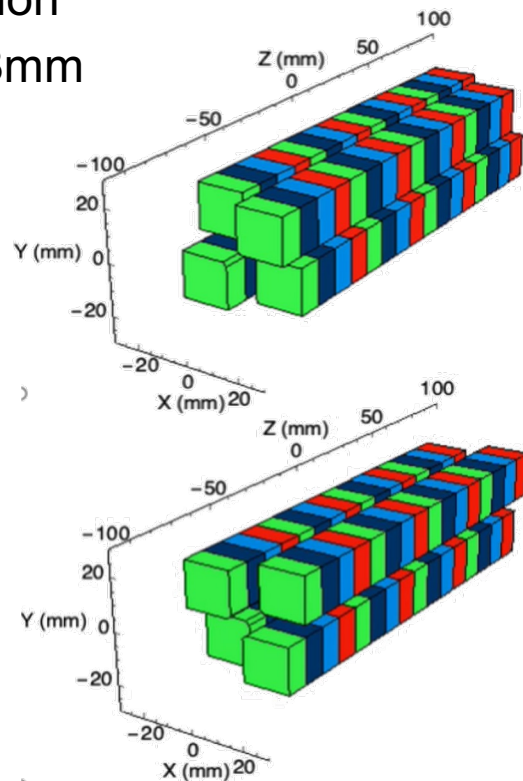
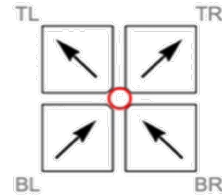
■ Radial: 6.25mm – 15.8mm

■ Shift for C+

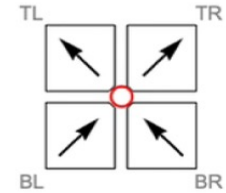
- ▶ TL: 11.25 mm
- ▶ TR: -11.25 mm
- ▶ BL: -11.25 mm
- ▶ BR: 11.25 mm

■ Shift for C-

- ▶ TL: -11.25 mm
- ▶ TR: 11.25 mm
- ▶ BL: 11.25 mm
- ▶ BR: -11.25 mm



APPLE-X undulators control – Polarization mode Linear Vertical (LV)



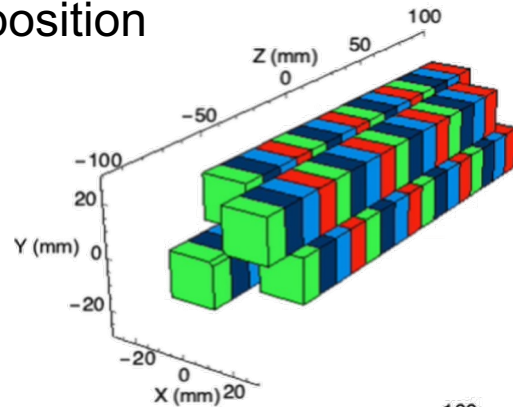
Linear Vertical girder position

Radial: 6.25mm – 15.8mm

Linear Vertical girder position

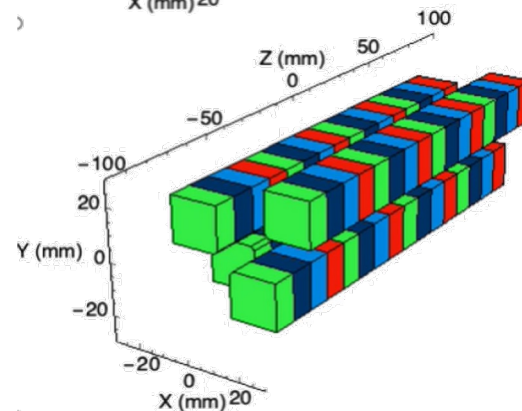
Shift for LV1

- ▶ TL: 22.5 mm
- ▶ TR: - 22.5 mm
- ▶ BL: - 22.5 mm
- ▶ BR: 22.5 mm



Shift for LV2

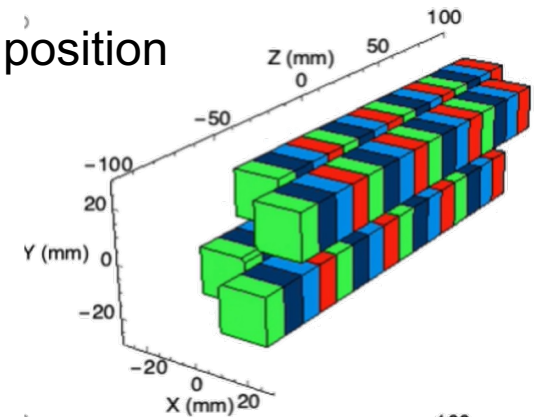
- ▶ TL: - 22.5 mm
- ▶ TR: 22.5 mm
- ▶ BL: 22.5 mm
- ▶ BR: - 22.5 mm



Linear Vertical girder position

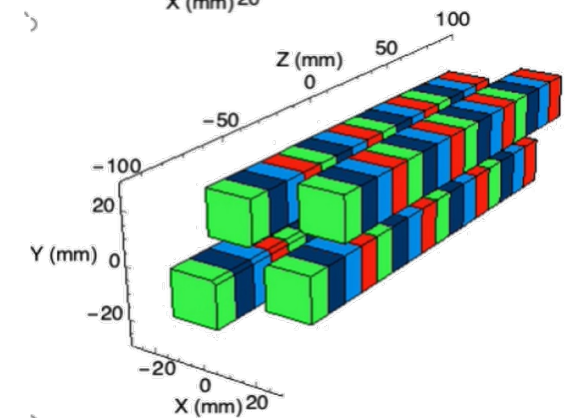
Shift for LV3

- ▶ TL: 45 mm
- ▶ TR: 0 mm
- ▶ BL: 0 mm
- ▶ BR: -45 mm



Shift for LV4

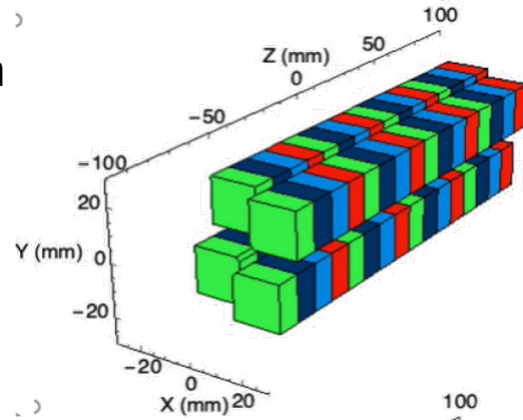
- ▶ TL: 0mm
- ▶ TR: 45 mm
- ▶ BL: -45 mm
- ▶ BR: 0 mm



APPLE-X undulators control – Polarization mode 45°, 135°, New 45°, New 135°

45°, 135° girder position

Radial symmetric: 6.25mm – 15.8mm



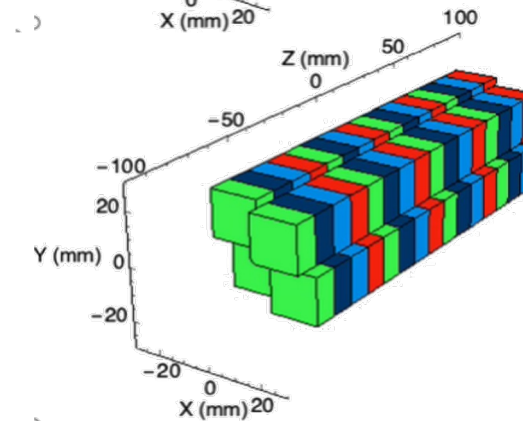
45°, 135° girder position

Shift for 45°

- ▶ TL: 22.5 mm
- ▶ TR: 0mm
- ▶ BL: 0 mm
- ▶ BR: -22.5 mm

Shift for 135°

- ▶ TL: 0 mm
- ▶ TR: 22.5 mm
- ▶ BL: -22.5 mm
- ▶ BR: 0 mm



New 45°:

Radial TL and BR = 15.8 mm

Radial: TR and BL: 6.25 mm – 15.8 mm

New 135°:

Radial TR and BL = 15.8 mm

Radial: TL and BR: 6.25 mm – 15.8 mm

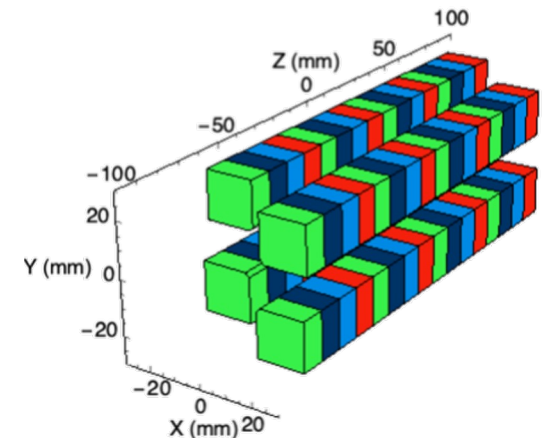
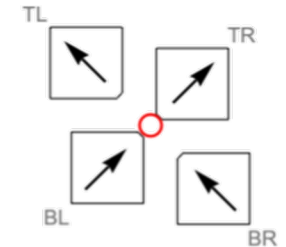
New 45°, New 135° girder position

Shift for New 45°

- ▶ TL: 22.5 mm
- ▶ TR: 0mm
- ▶ BL: 0 mm
- ▶ BR: -22.5 mm

Shift for New 135°

- ▶ TL: 0 mm
- ▶ TR: 22.5 mm
- ▶ BL: -22.5 mm
- ▶ BR: 0 mm

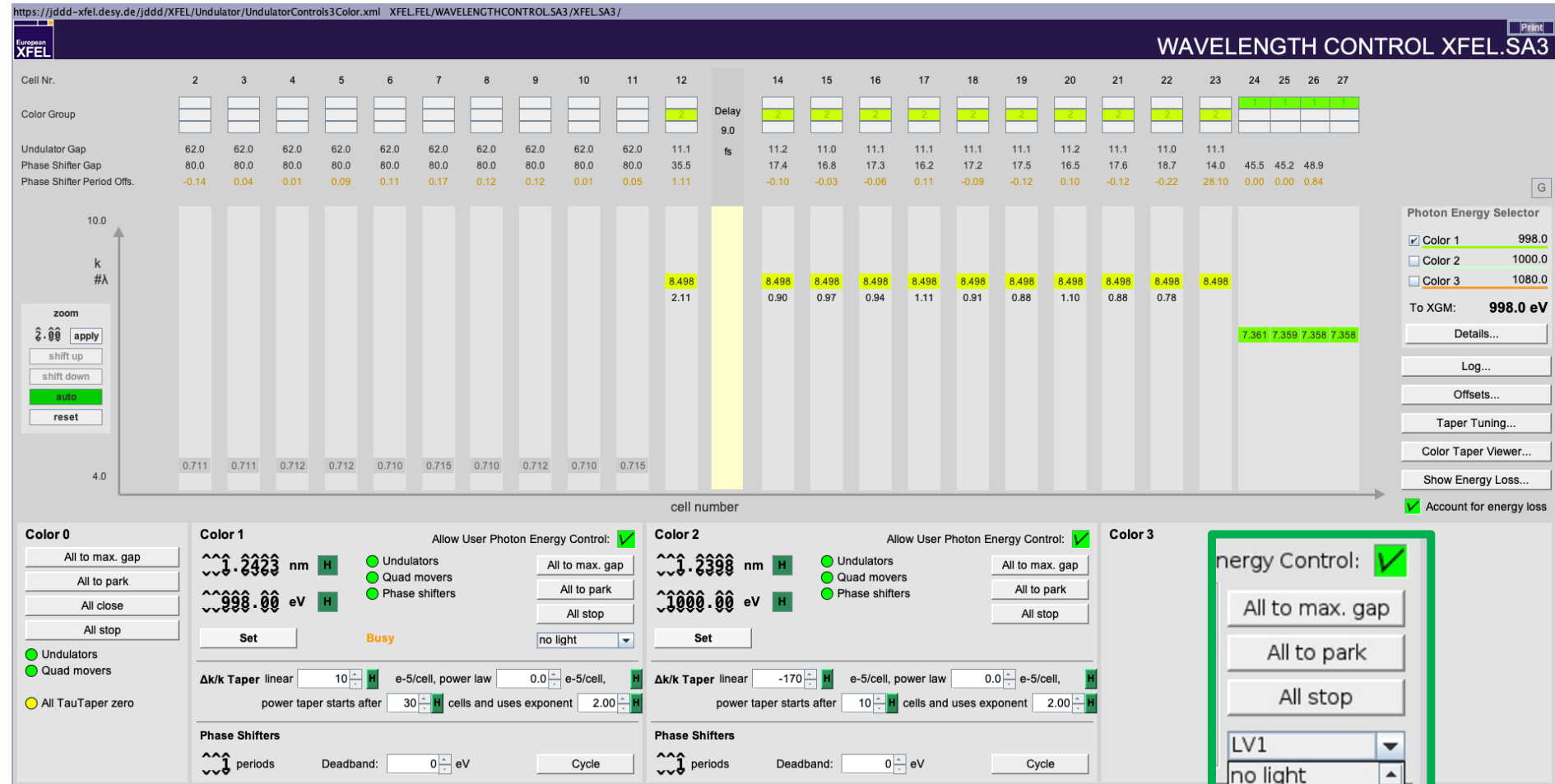


APPLE-X undulators control - SASE3 wavelength control panel

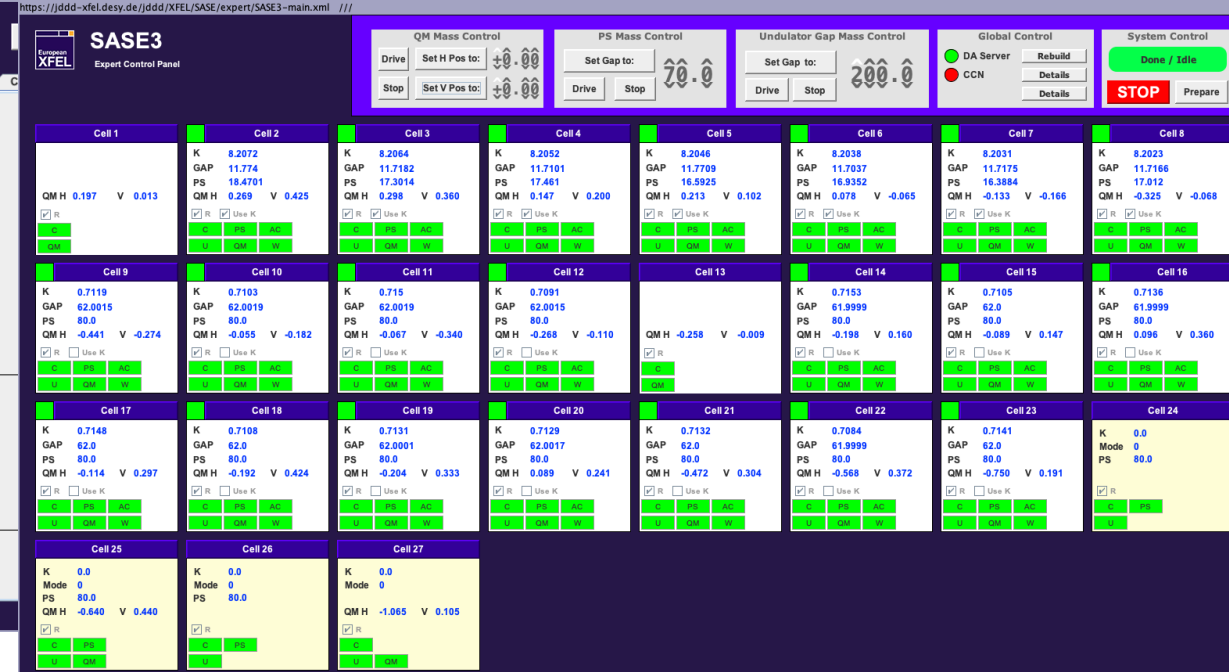
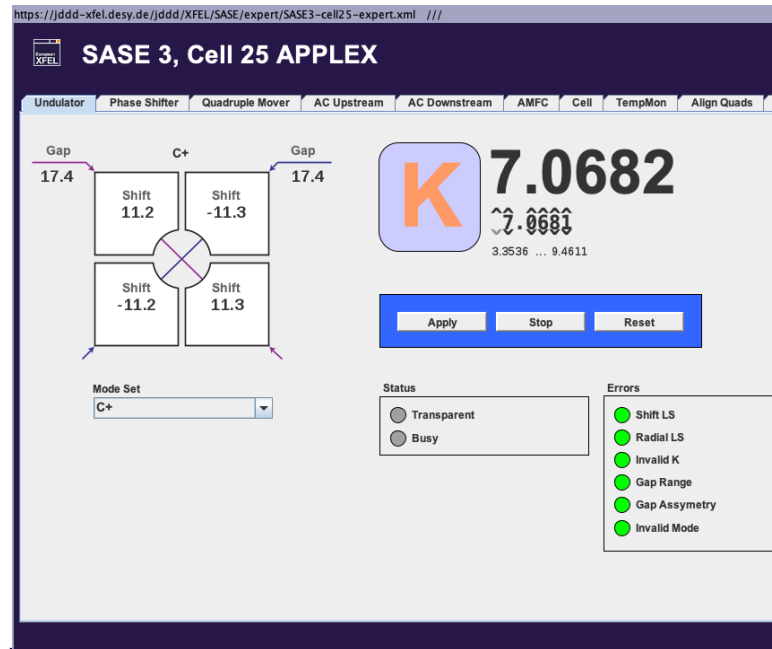
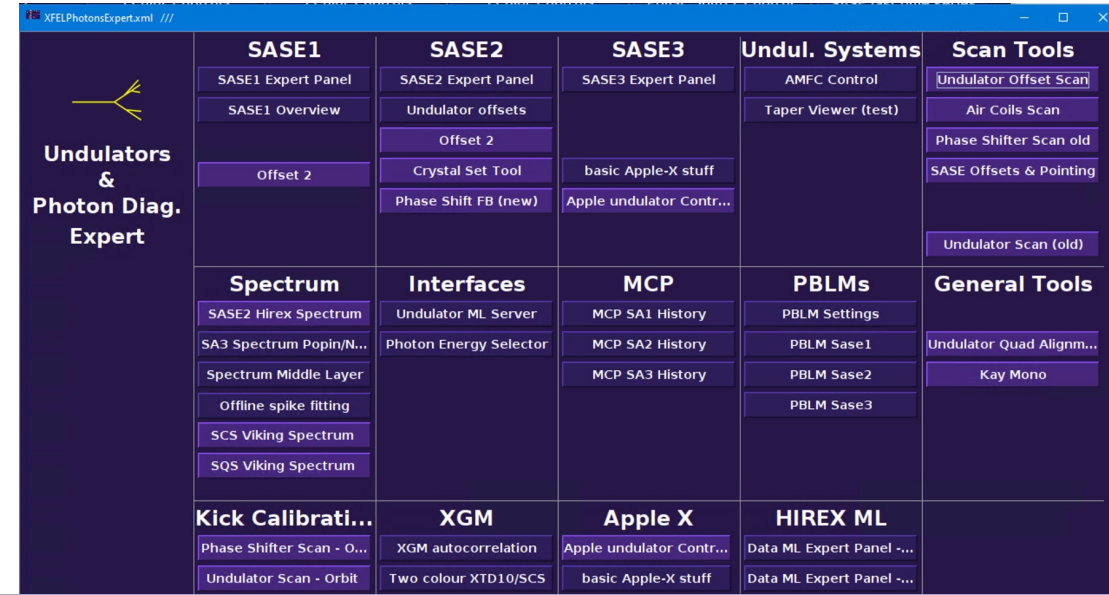
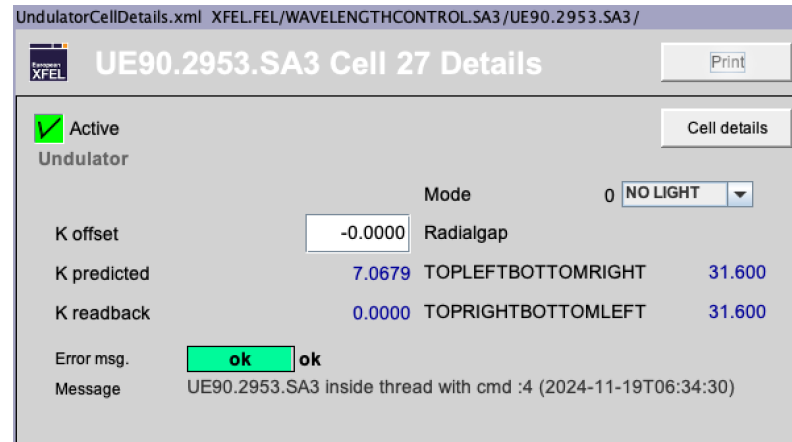
SASE3

wavelength control panel offers the following selection options

- Color group
- Polarization mode
- Photon energy
- Phase Shifter Period selection
- Taper type and parameters selection



APPLE-X undulators control – Expert panels



APPLE-X undulators control – Expert panel for a cell: Undulator tab

The screenshot shows the 'SASE 3, Cell 25 APPLE-X' expert panel. The interface includes a top navigation bar with tabs: Undulator, Phase Shifter, Quadruple Mover, AC Upstream, AC Downstream, AMFC, Cell, TempMon, Align Quads, and Cam Mover. The 'Undulator' tab is active. The main display area shows a schematic of the undulator with four quadrants labeled 'Shift 11.2', 'Shift -11.3', 'Shift -11.2', and 'Shift 11.3'. The 'Gap' is set to 17.4. A large 'K' icon is displayed next to the value 7.0682, with a range of 3.3536 to 9.4611. Below this are 'Apply', 'Stop', and 'Reset' buttons. A 'Mode Set' dropdown menu is set to 'C+'. A 'Status' section shows 'Transparent' and 'Busy' indicators. An 'Errors' section lists: Shift LS, Radial LS, Invalid K, Gap Range, Gap Assymetry, and Invalid Mode. A 'Print' button is in the top right corner.

Annotations on the left side:

- Actual polarization mode
- Actual gap value
- Actual shift position of the magnet girder
- Polarization selection mode

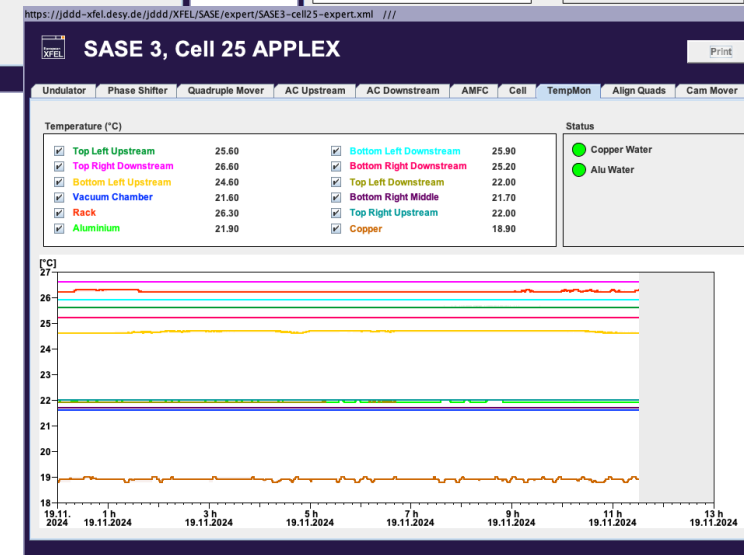
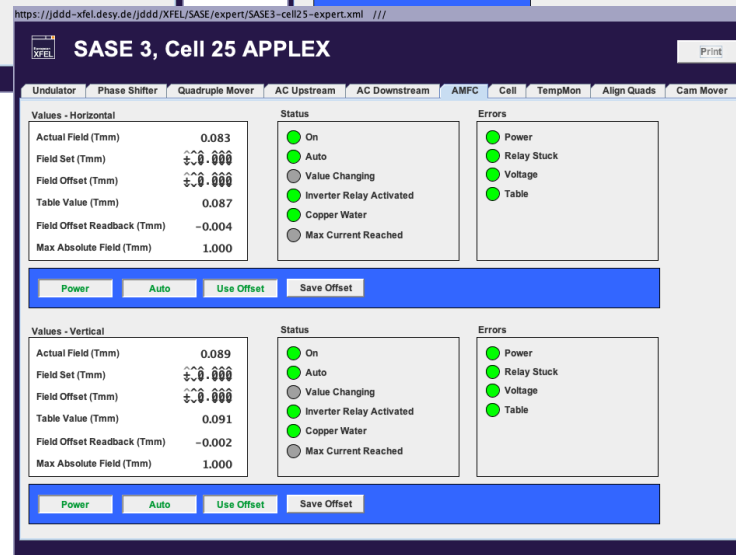
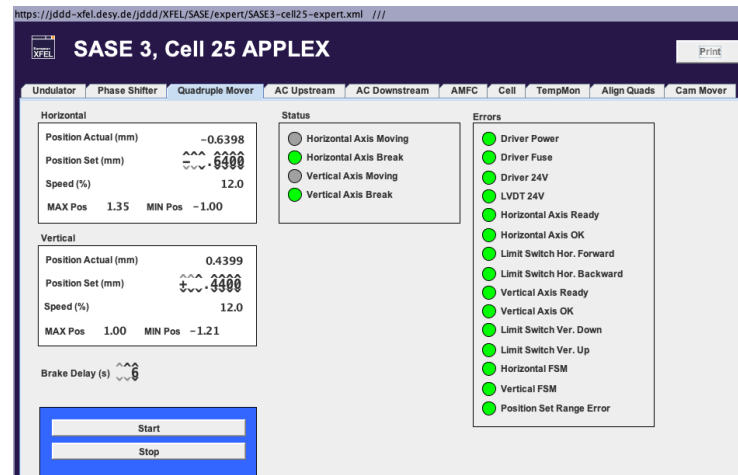
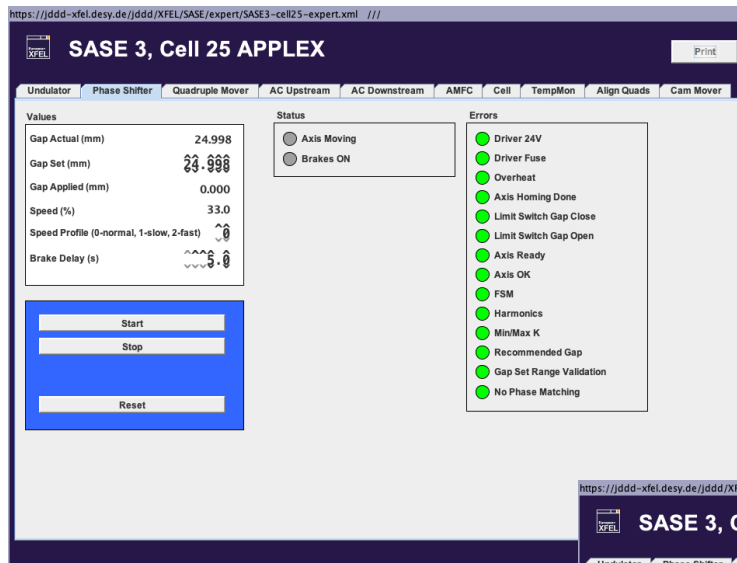
Annotations on the right side:

- K Actual
- K Set
- K range for selected polarization mode
- Control buttons
- Status indicators
- Error indicators

European XFEL

APPLE-X undulators control – Expert panel for a cell

- The tabs: Phase Shifter, Quadrupole Mover, Air Coils Upstream/Downstream, Ambient Magnetic Field Corrector, Cell and Temperature are like in case of the planar undulator controls



APPLE-X undulators control – New panels: Alignment Quadrupole, Cam Mover

https://jddd-xfel.desy.de/jddd/XFEL/SASE/expert/SASE3-cell25-expert.xml ///

SASE 3, Cell 25 APPLE-X Print

Undulator Phase Shifter Quadruple Mover AC Upstream AC Downstream AMFC Cell TempMon Align Quads **Cam Mover**

Positional Values		Angular Values		Tilt Safety	
X (mm)	-0.363	Roll (mrad)	0.287	Actual Tilt (mrad)	0.040
X Set (mm)	$\hat{0}.425$	Roll Set (mrad)	$\hat{0}.041$	Warning Tilt (mrad)	0.060
Y (mm)	0.562	Yaw (mrad)	0.065	Stop Tilt (mrad)	0.100
Y Set (mm)	$\hat{0}.500$	Yaw Set (mrad)	$\hat{0}.120$		
		Pitch (mrad)	0.013		
		Pitch Set (mrad)	$\hat{0}.050$		

Motors On Motors Off Start Stop

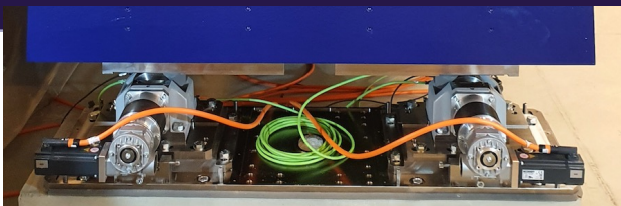
- The purpose of the system is to adjust the magnetic axis of the undulator relative to the orbit of the e-beam.
- Alignment quadrupoles only need to be inserted when aligning the undulator.
- Operation of the cam movers is deactivated for global control to prevent possible damage to the vacuum system.

Status

- ☐ Moving
- ☐ Soft Limit Status
- ☐ Power Motor 1
- ☐ Power Motor 2
- ☐ Power Motor 3
- ☐ Power Motor 4
- ☐ Power Motor 5

Errors

- ☒ Soft Limit Stop
- ☒ Soft Limit Inhibit
- ☒ Tilt Sensor Error
- ☒ Tilt Warning Zone
- ☒ Tilt Stop
- ☒ Invalid Set Value(s)



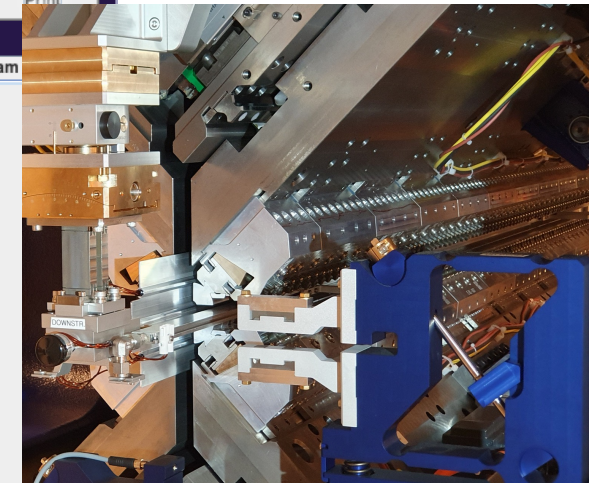
https://jddd-xfel.desy.de/jddd/XFEL/SASE/expert/SASE3-cell25-expert.xml ///

SASE 3, Cell 25 APPLE-X Print

Undulator Phase Shifter Quadruple Mover AC Upstream AC Downstream AMFC Cell TempMon **Align Quads** Cam

Upstream	Downstream
☒ Out of Beam	☒ Out of Beam
☐ In Beam	☐ In Beam
☐ Busy	☐ Busy
☒ Error	☒ Error
☒ Air Pressure Control	☒ Air Pressure Control

Insert Retract Reset



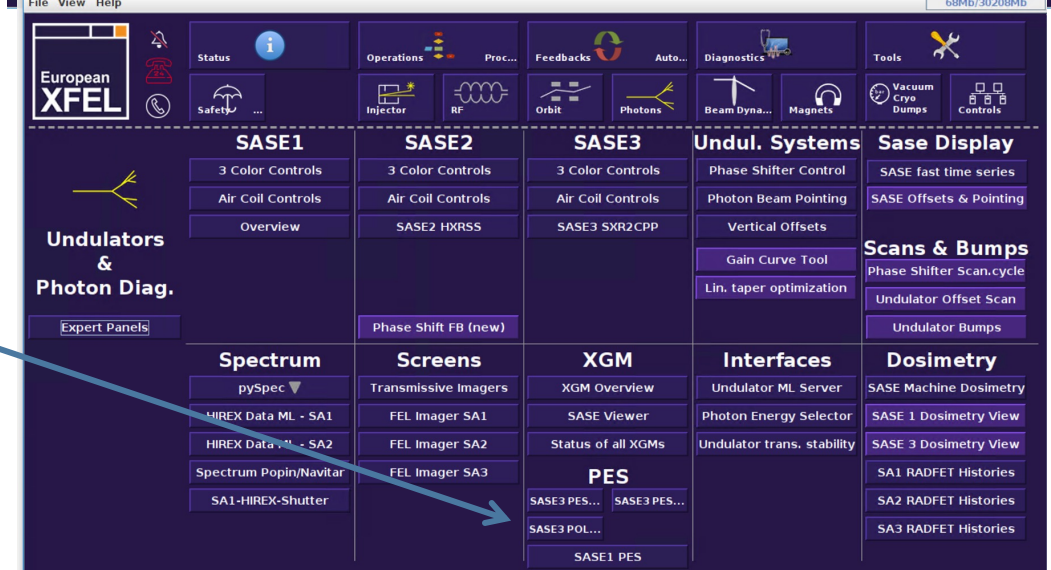
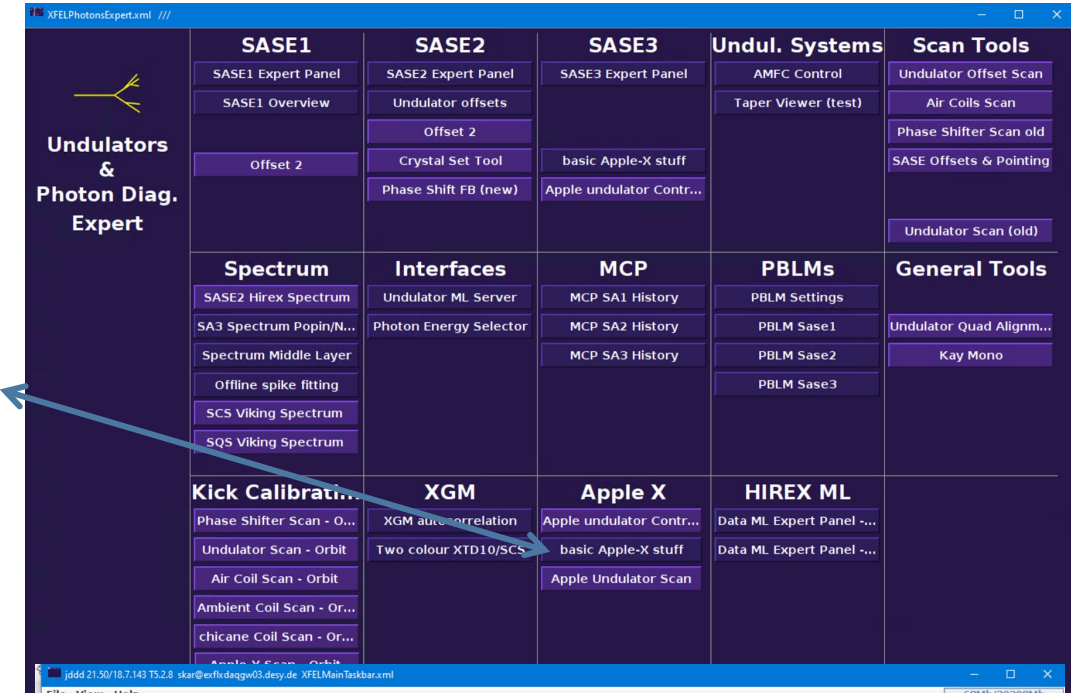
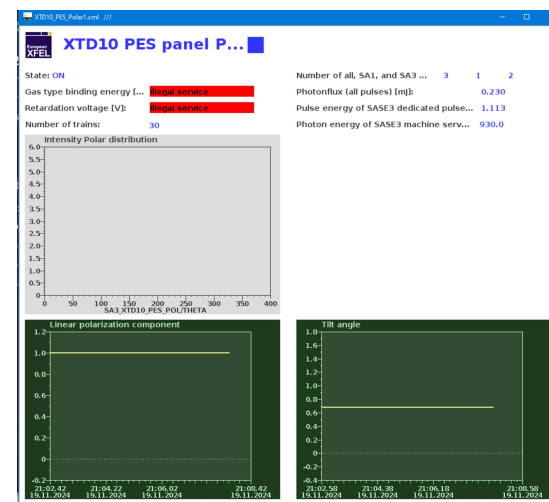
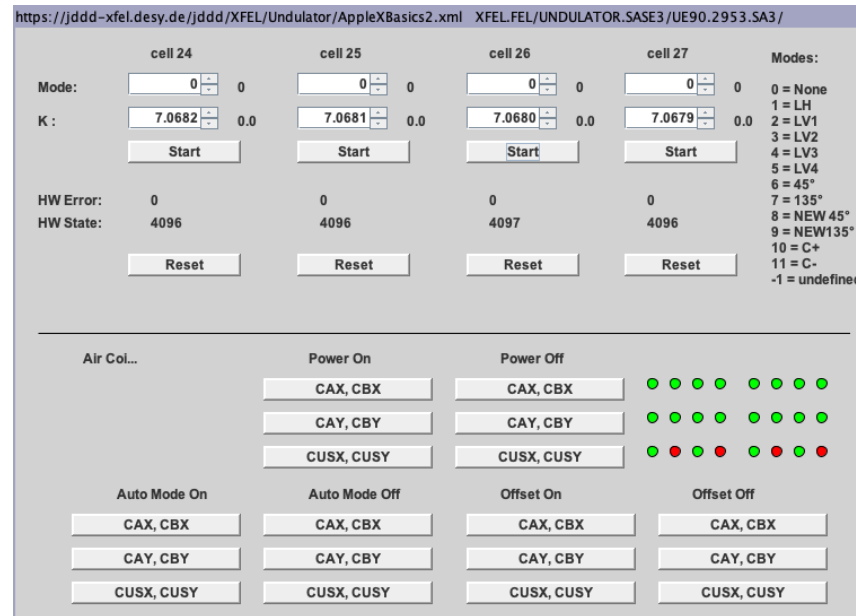
APPLE-X undulators – Useful panels

Expert Panel -
Basic Apple-X
stuff

Correction
coils control
and status
overview

Photons panel –
PES – SASE3
Pol.

Polarization
online
diagnostic



Thank you for your attention!

