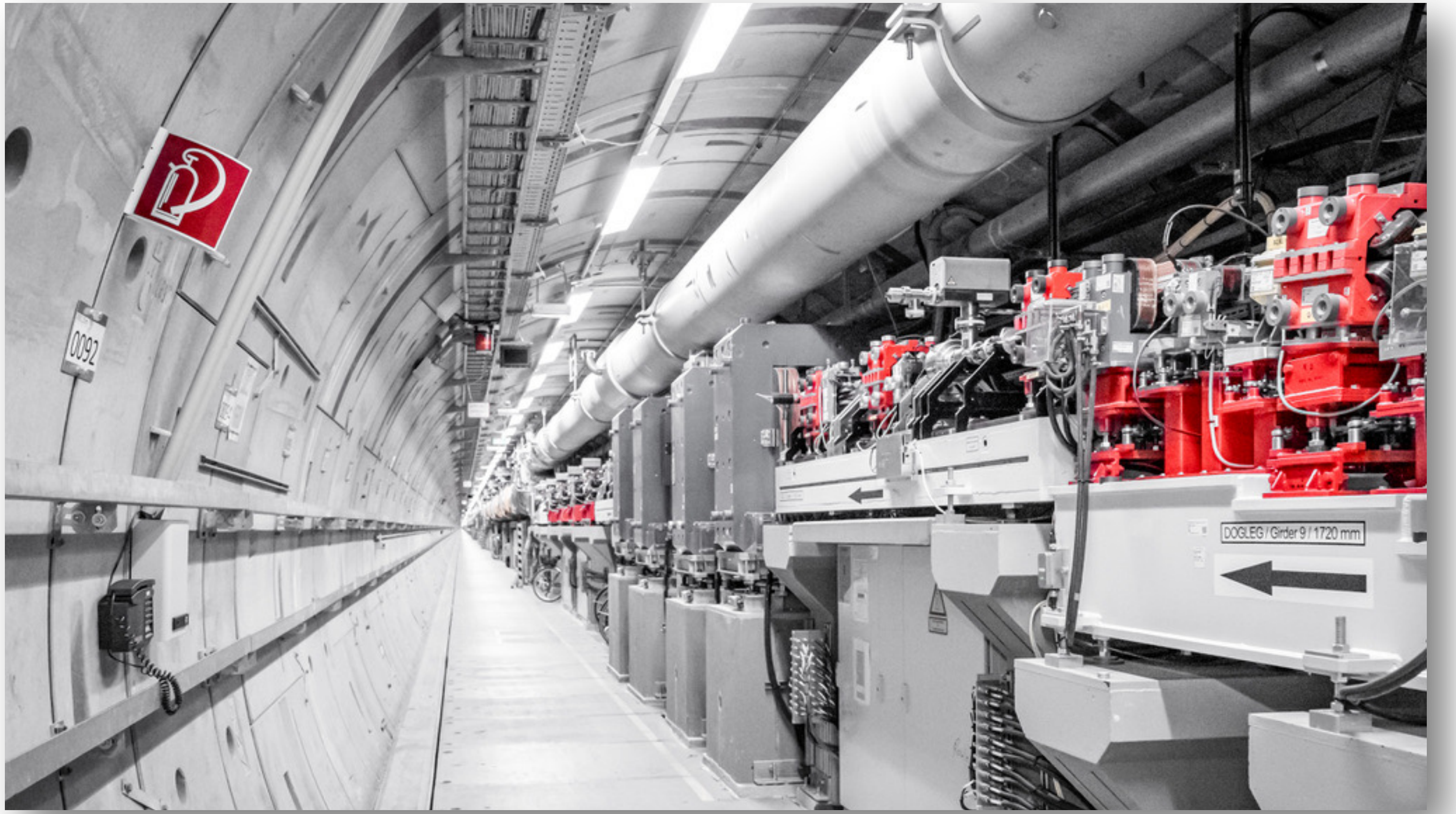
XFEL Accelerator: Status and setup

Matthias Scholz on behalf of the accelerator team



European XFEL

DESY.

HELMHOLTZ

Content

- Status of the Accelerator right now (short and painless)
- Restart dates (to the best of our knowledge and beliefs)
- Accelerator setup: the how, the why, and the occasional why-not

2025 Operation Schedule

- Covered electron beam energies:
  - 10.5 GeV (1 week)
  - 12 GeV (3 weeks)
  - 14 GeV (7 weeks)
  - 16 GeV (5 weeks)
- Operation until mid of June 2025
- Long Installation and Maintenance Period (LIMP) since.
- Operation highlights were reported by Andreas.

European XFEL

Operation Schedule 2025

Shutdown/Maintenance; Linac startup; Interlock tests (no beam); Facility development; Access, setup, tuning; Experiment tuning; X-ray program (8 GeV, 10.5 GeV, 11.5 GeV, 14 GeV, 16.1 GeV, 16.3 GeV, 250 pC, 4.5 MHz).
Special mode: Short Pulse, HXRSS, Two Colour

2025	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Jan	We	Th	Fr	Sa	Su	wk2 Mo	Tu	We	Th	Fr	Sa	Su	wk3 Mo	Tu	We	Th
Feb	Sa 14.0G ET	Su 14.0G ET	wk6 Mo 14.0G ET	Tu	We 14.0G	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G	wk7 Mo 14.0G	Tu	We 14.0G	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G
March	Sa 14.0G	Su 14.0G	wk10 Mo 14.0G	Tu	We	Th	Fr	Sa	Su	wk11 Mo	Tu	We 16.3G	Th 16.3G	Fr 16.3G	Sa 16.3G	Su 16.3G
Apr	Tu	We 16.3G	Th 16.3G	Fr 16.3G	Sa 16.3G	Su 16.3G	wk15 Mo 16.3G	Tu	We 16.3G	Th 16.3G	Fr 16.3G	Sa 16.3G	Su 16.3G	wk16 Mo 16.3G	Tu	We
May	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G	wk19 Mo 14.0G	Tu	We 14.0G	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G	wk20 Mo 14.0G	Tu	We	Th	Fr
June	Su 12.0G	wk23 Mo 12.0G	Tu	We 12.0G	Th 12.0G	Fr 12.0G	Sa 12.0G	Su 12.0G	wk24 Mo 12.0G	Tu	We 10.5G	Th 10.5G	Fr 10.5G	Sa 10.5G	Su 10.5G	wk25 Mo 10.5G
July	Tu	We	Th	Fr	Sa	Su	wk28 Mo	Tu	We	Th	Fr	Sa	Su	wk29 Mo	Tu	We
Aug	Fr	Sa	Su	wk32 Mo	Tu	We	Th	Fr	Sa	Su	wk33 Mo	Tu	We	Th	Fr	Sa
Sept	wk36 Mo	Tu	We	Th	Fr	Sa	Su	wk37 Mo	Tu	We	Th	Fr	Sa	Su	wk38 Mo	Tu
Oct	We	Th	Fr	Sa	Su	wk41 Mo	Tu	We	Th	Fr	Sa	Su	wk42 Mo	Tu	We	Th
Nov	Sa	Su	wk45 Mo	Tu	We	Th	Fr	Sa	Su	wk46 Mo	Tu	We	Th	Fr	Sa	Su
Dec	wk49 Mo	Tu	We	Th	Fr	Sa	Su	wk50 Mo	Tu	We	Th	Fr	Sa	Su	wk51 Mo	Tu
Jan 2026	Th	Fr	Sa	Su	wk2 Mo	Tu	We	Th	Fr	Sa	Su	wk3 Mo	Tu	We	Th	Fr

2025	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan	Fr	Sa	Su	wk4 Mo	Tu	We	Th	Fr	Sa	Su	wk5 Mo	Tu	We 14.0G ET	Th 14.0G ET	Fr 14.0G ET
Feb	wk8 Mo 14.0G	Tu	We 14.0G	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G	wk9 Mo 14.0G	Tu	We 14.0G	Th 14.0G	Fr 14.0G			
March	wk12 Mo 16.3G	Tu	We 16.3G	Th 16.3G	Fr 16.3G	Sa 16.3G	Su 16.3G	wk13 Mo 16.3G	Tu	We 16.3G	Th 16.3G	Fr 16.3G	Sa 16.3G	Su 16.3G	wk14 Mo 16.3G
Apr	Th	Fr	Sa	Su	wk17 Mo	Tu	We 14.0G	Th 14.0G	Fr 14.0G	Sa 14.0G	Su 14.0G	wk18 Mo 14.0G	Tu	We 14.0G	
May	Sa	Su	wk21 Mo	Tu	We 12.0G	Th 12.0G	Fr 12.0G	Sa 12.0G	Su 12.0G	wk22 Mo 12.0G	Tu	We 12.0G	Th 12.0G	Fr 12.0G	Sa 12.0G
June	Tu	We	Th	Fr	Sa	Su	wk26 Mo	Tu	We	Th	Fr	Sa	Su	wk27 Mo	
July	Th	Fr	Sa	Su	wk30 Mo	Tu	We	Th	Fr	Sa	Su	wk31 Mo	Tu	We	Th
Aug	Su	wk34 Mo	Tu	We	Th	Fr	Sa	Su	wk35 Mo	Tu	We	Th	Fr	Sa	Su
Sept	We	Th	Fr	Sa	Su	wk39 Mo	Tu	We	Th	Fr	Sa	Su	wk40 Mo	Tu	
Oct	Fr	Sa	Su	wk43 Mo	Tu	We	Th	Fr	Sa	Su	wk44 Mo	Tu	We	Th	Fr
Nov	wk47 Mo	Tu	We	Th	Fr	Sa	Su	wk48 Mo	Tu	We	Th	Fr	Sa	Su	
Dec	We	Th	Fr	Sa	Su	wk52 Mo	Tu	We	Th	Fr	Sa	Su	wk1 Mo	Tu	We
Jan 2026	Sa	Su	wk4 Mo	Tu	We	Th	Fr	Sa	Su	wk5 Mo	Tu	We	Th	Fr	Sa

version 31.10.2024

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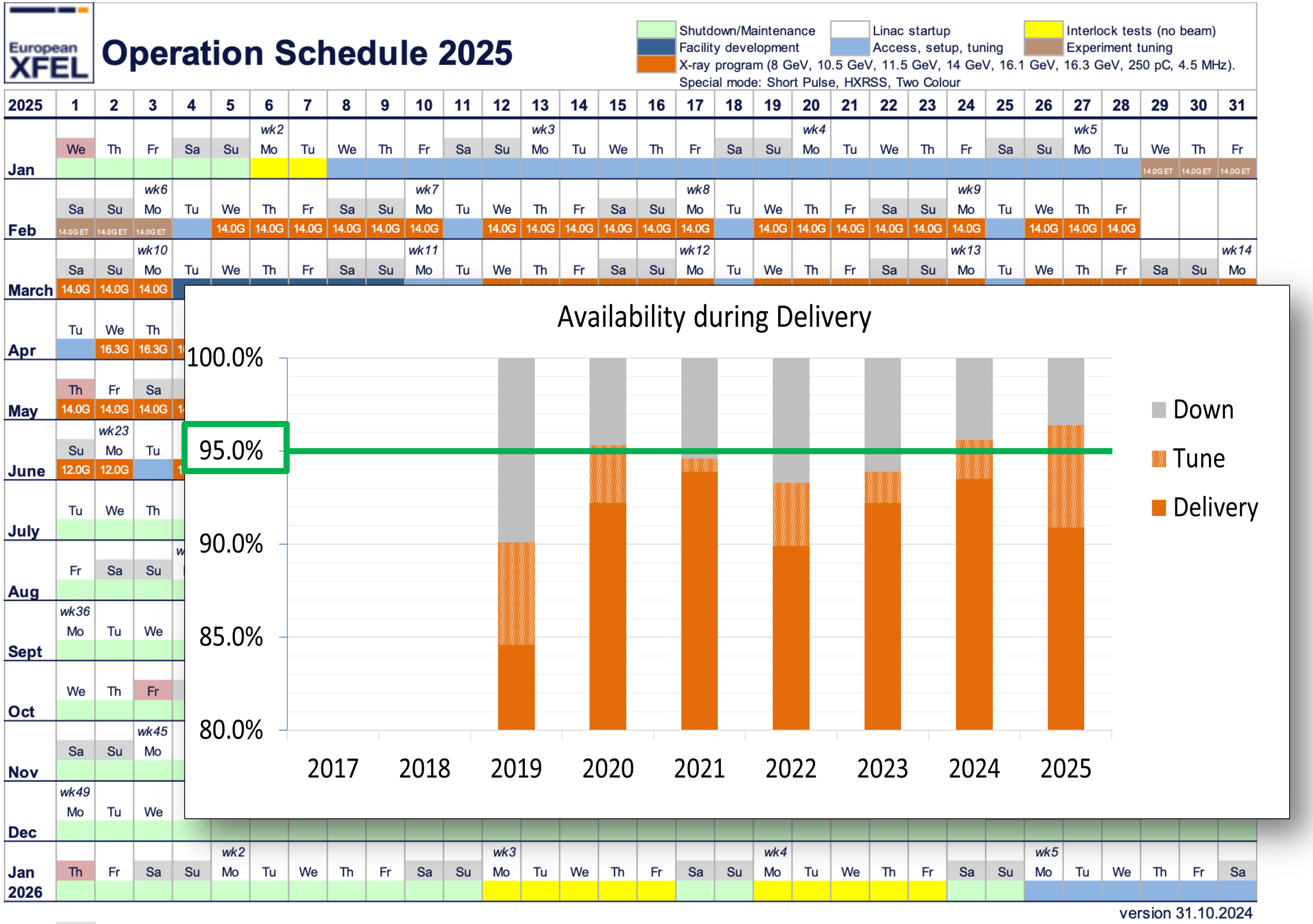

LIMP Activities Overview

1. Cryogenic Safety Valves
2. Gun5 Installation
3. SCU preparation (XTD1, SASE2)
4. ASPECT (XTD2, SASE1)
5. Streaker North (XTD4)
6. STERN (XS4 – XTD8)
7. HXRSS in SASE1
8. Additional magnet movers upstream SA1 & SA2

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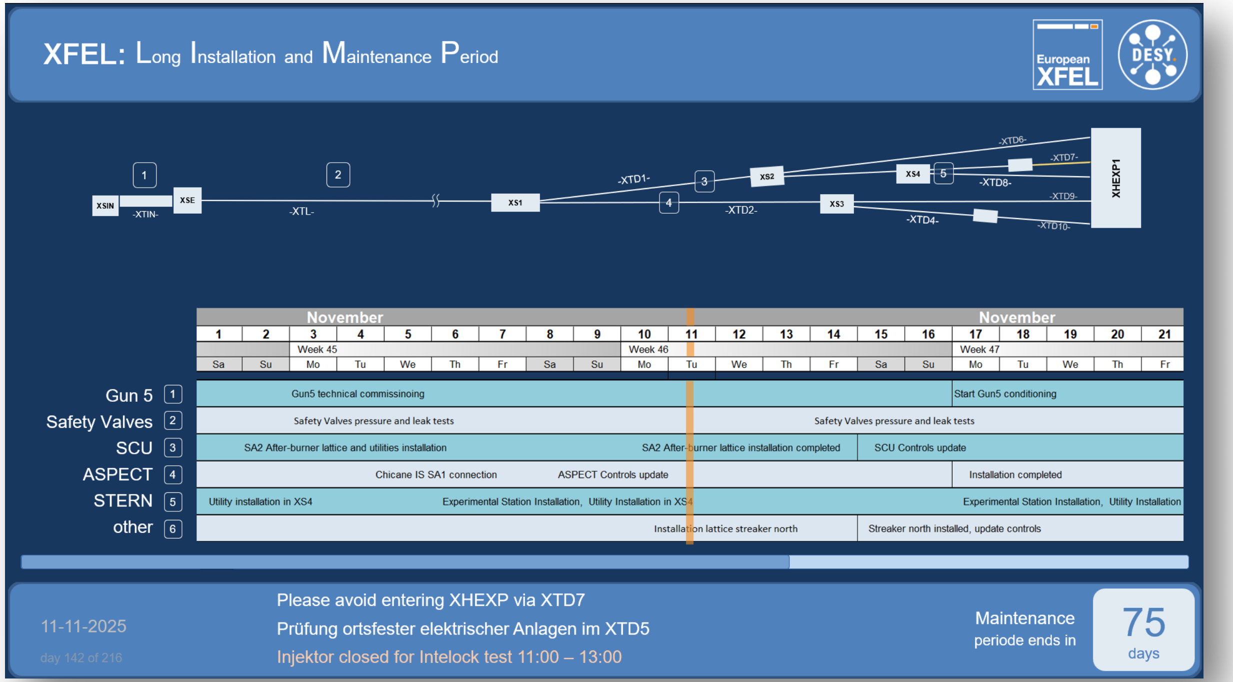

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10. Plus all the installations in the photon beamlines

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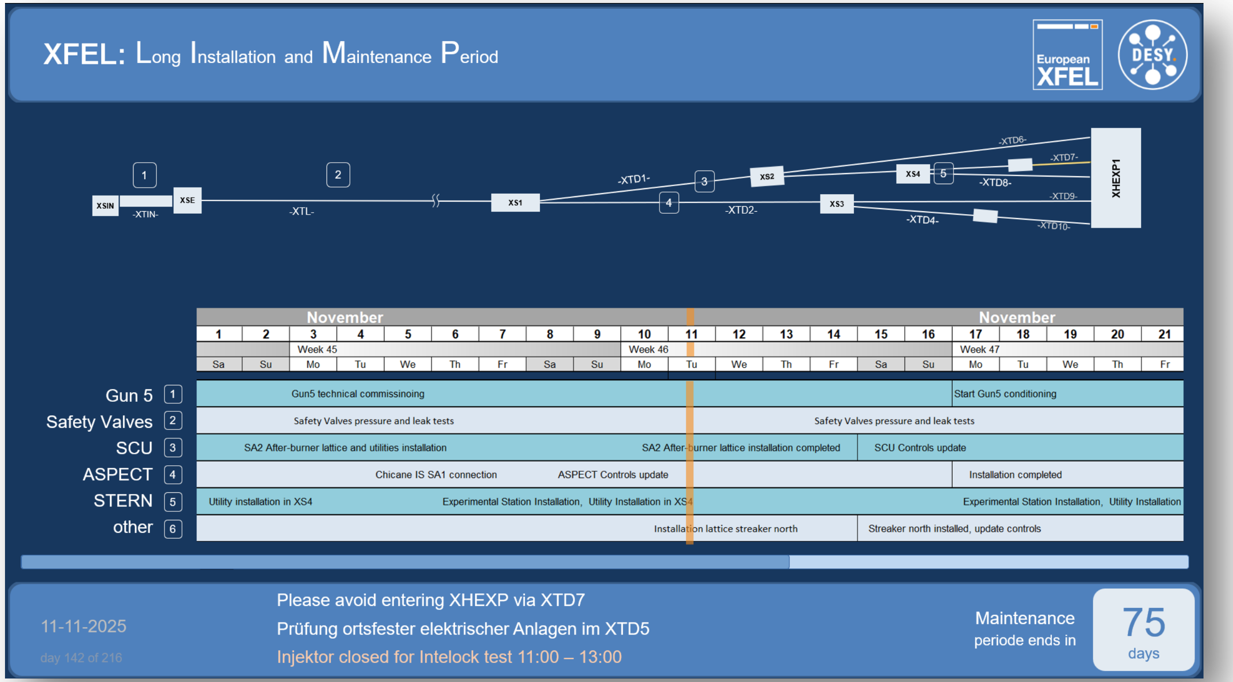

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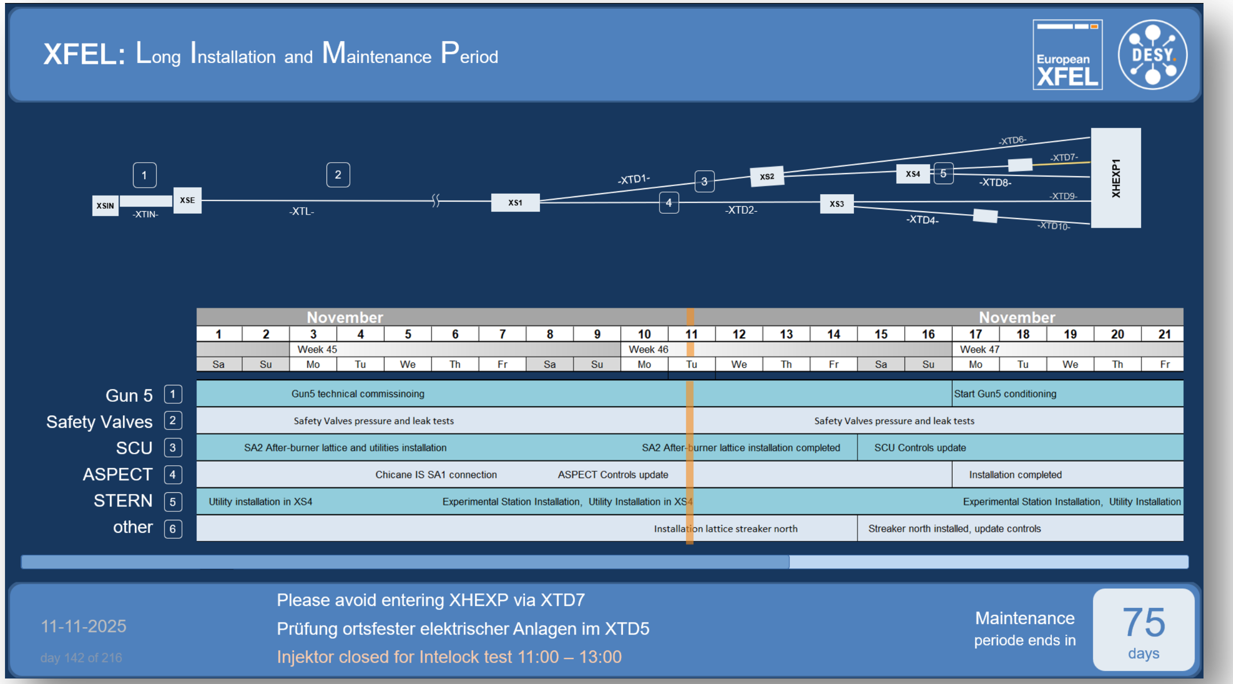

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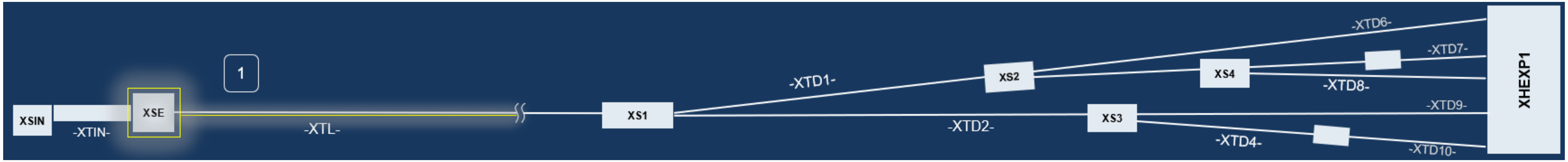
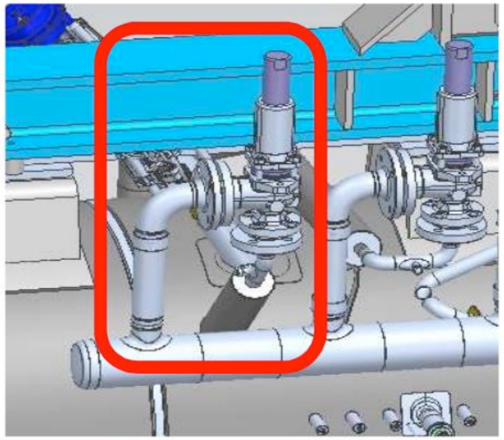
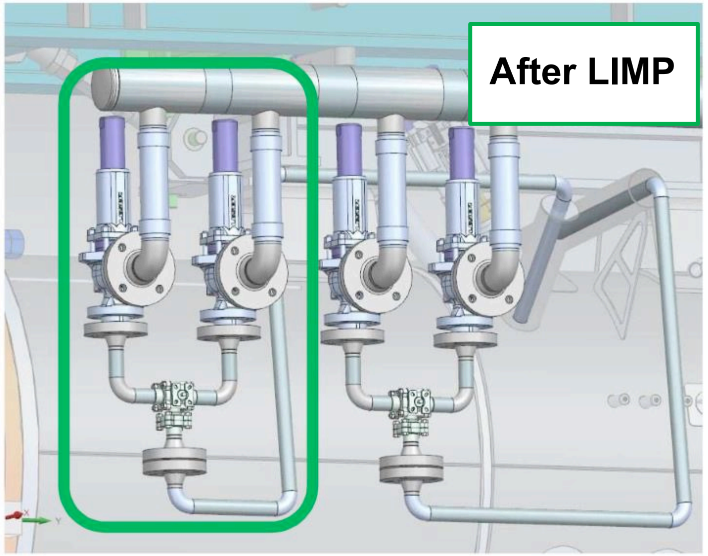


Safety Valve Exchange

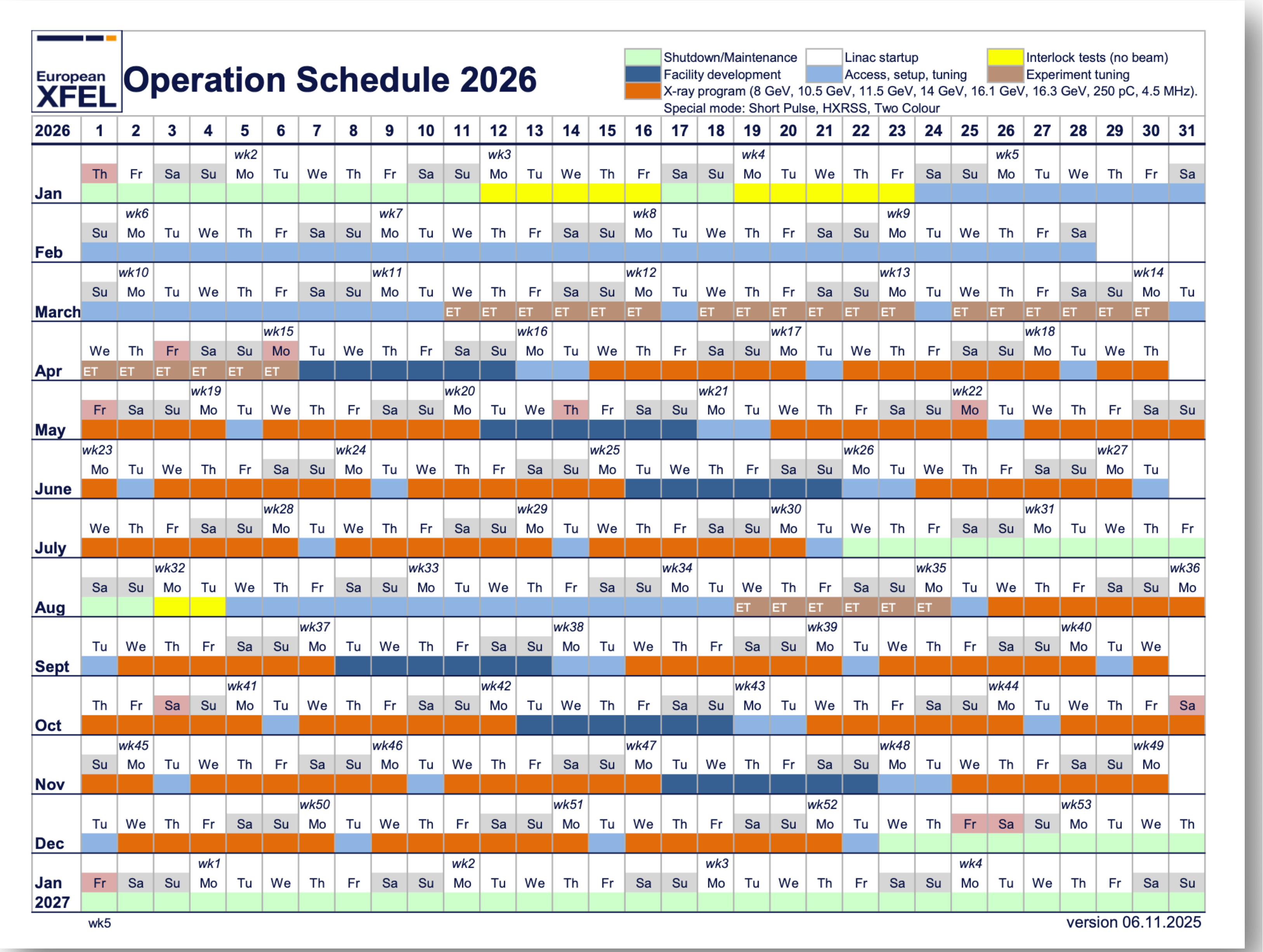
- SC linac and the cryogenic system: certified according to Pressure Equipment Directive
- The layout of the cryogenic system must ensure both machine safety and personnel safety in the event of a sudden evaporation of the liquid helium.
- Authorities require a test of the safety valves every 5 years through a certified body.
  - So far: single valve system -> requires a warm-up of the linac for maintenance.
  - change to a 2-valve system -> safety check, maintenance in the future without warmup.





2026 Operation Schedule

- Gun 5 conditioning can start next week.
- Linac cooldown can start on December 12, 2025
- The linac will be cold on January 26, 2026
- It is expected that we need about 2 weeks for cavity conditioning. -> Linac ready by mid February.
- Operation of upstream sections (e.g. injector) can start slightly earlier.
- 3-4 weeks of accelerator setup
- 4 weeks for experiment tuning
- First users in mid April
- Max 14 GeV e-beam energy during user runs until August.

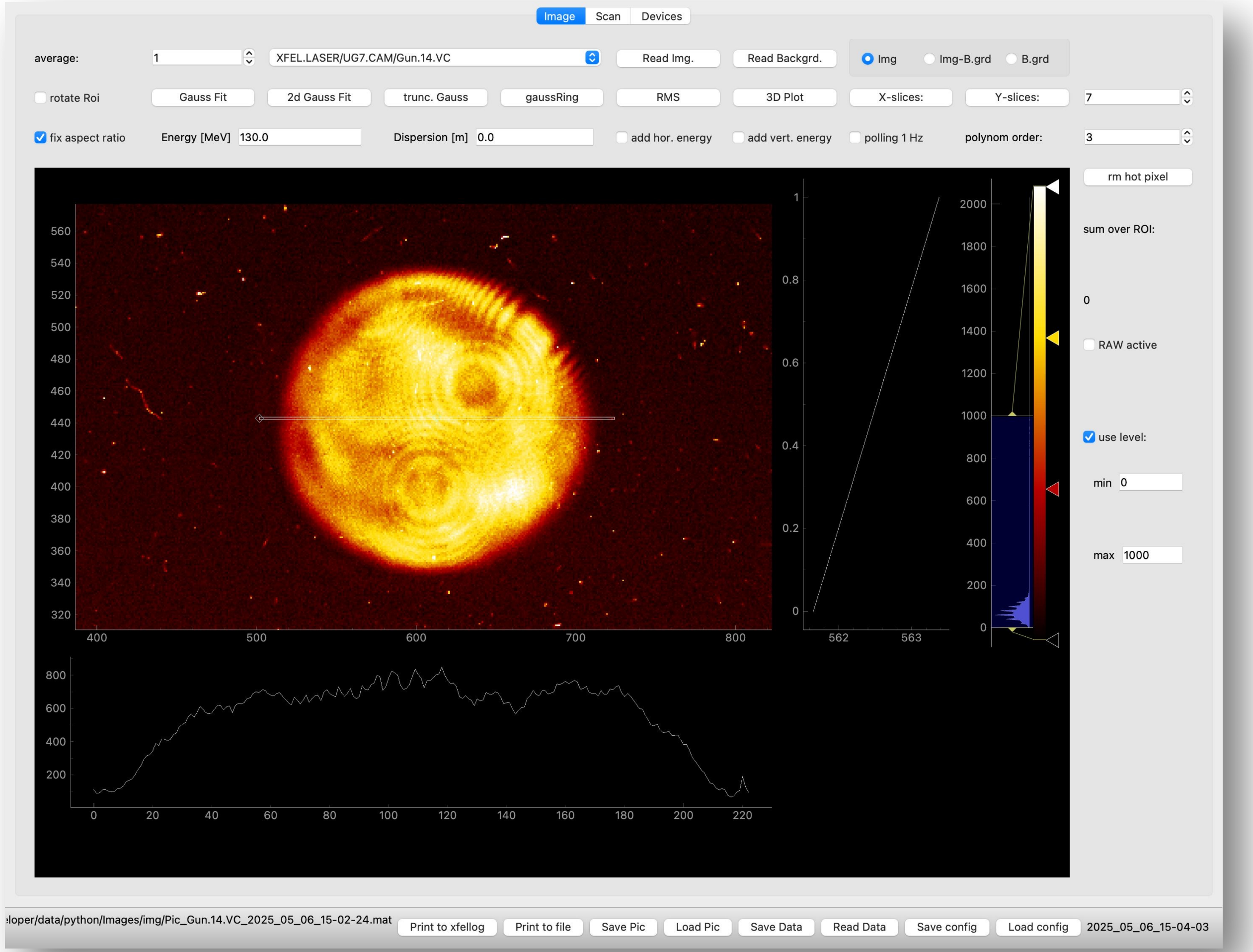


Accelerator preparation for photon delivery

- All individual steps
- Difficulties and how we deal with them
- Explanation why the setup can be time consuming

Laser on the cathode

- Checking the injector laser spot on the virtual cathode to ensure that the shape and homogeneity are ok.



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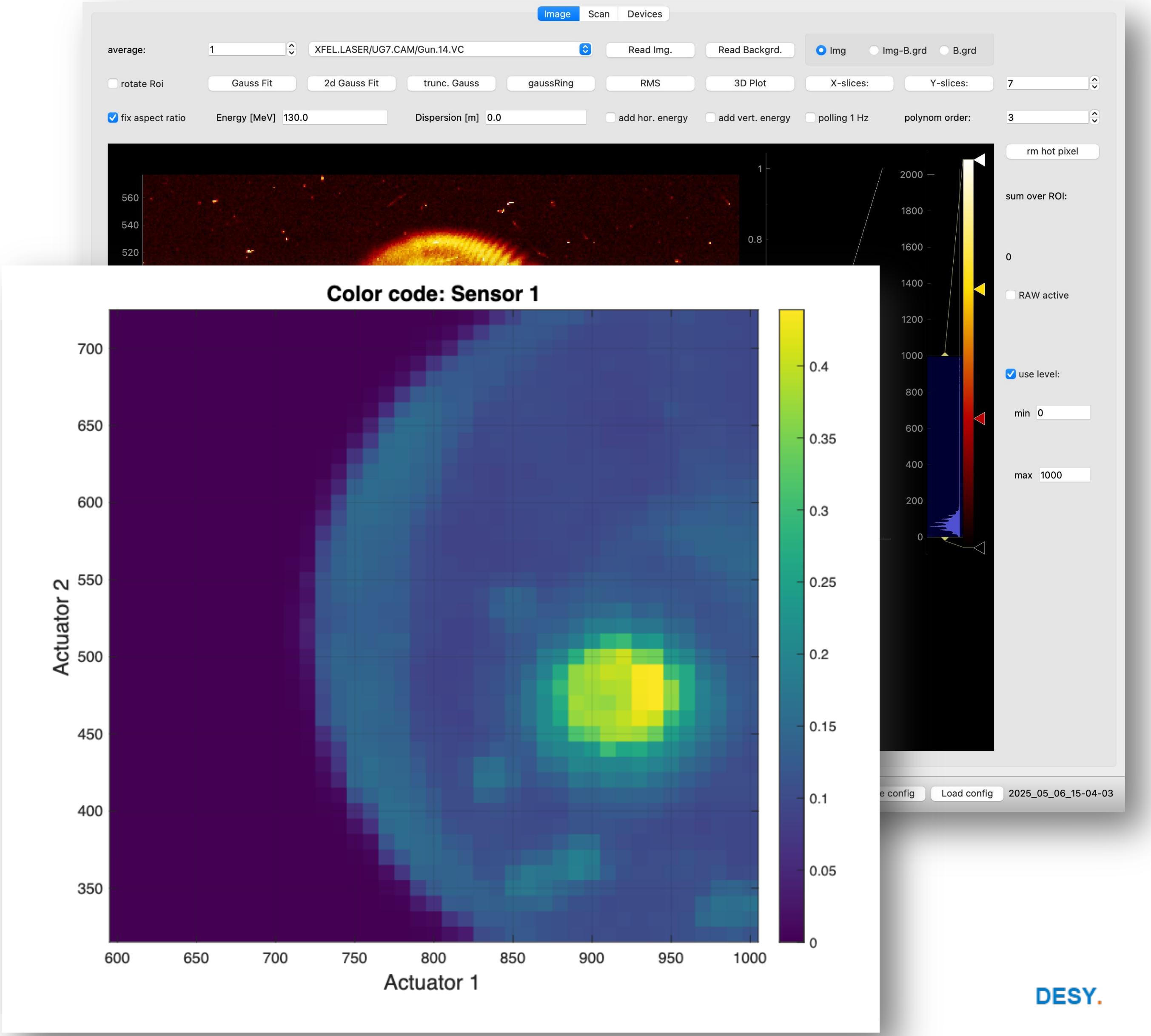
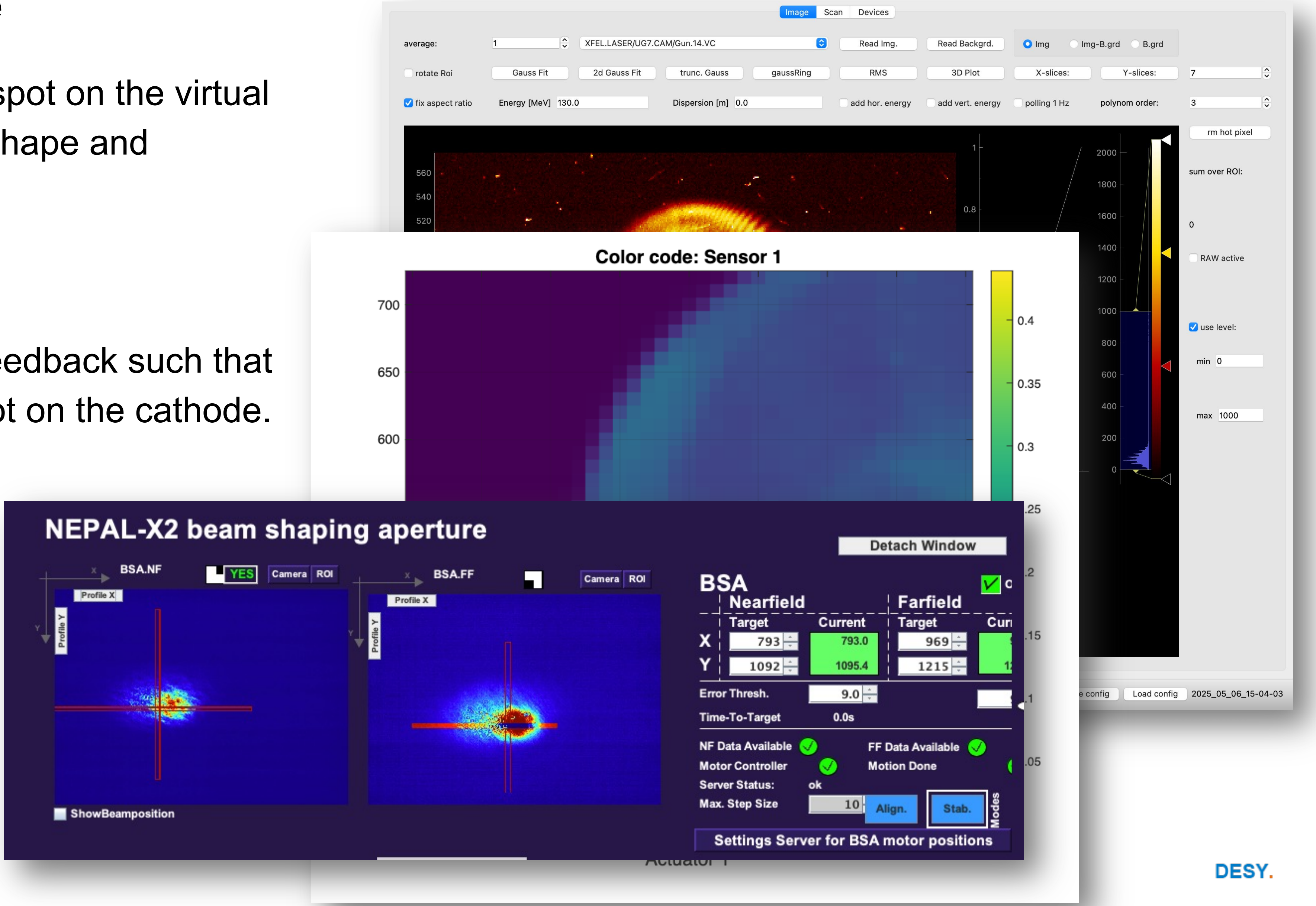


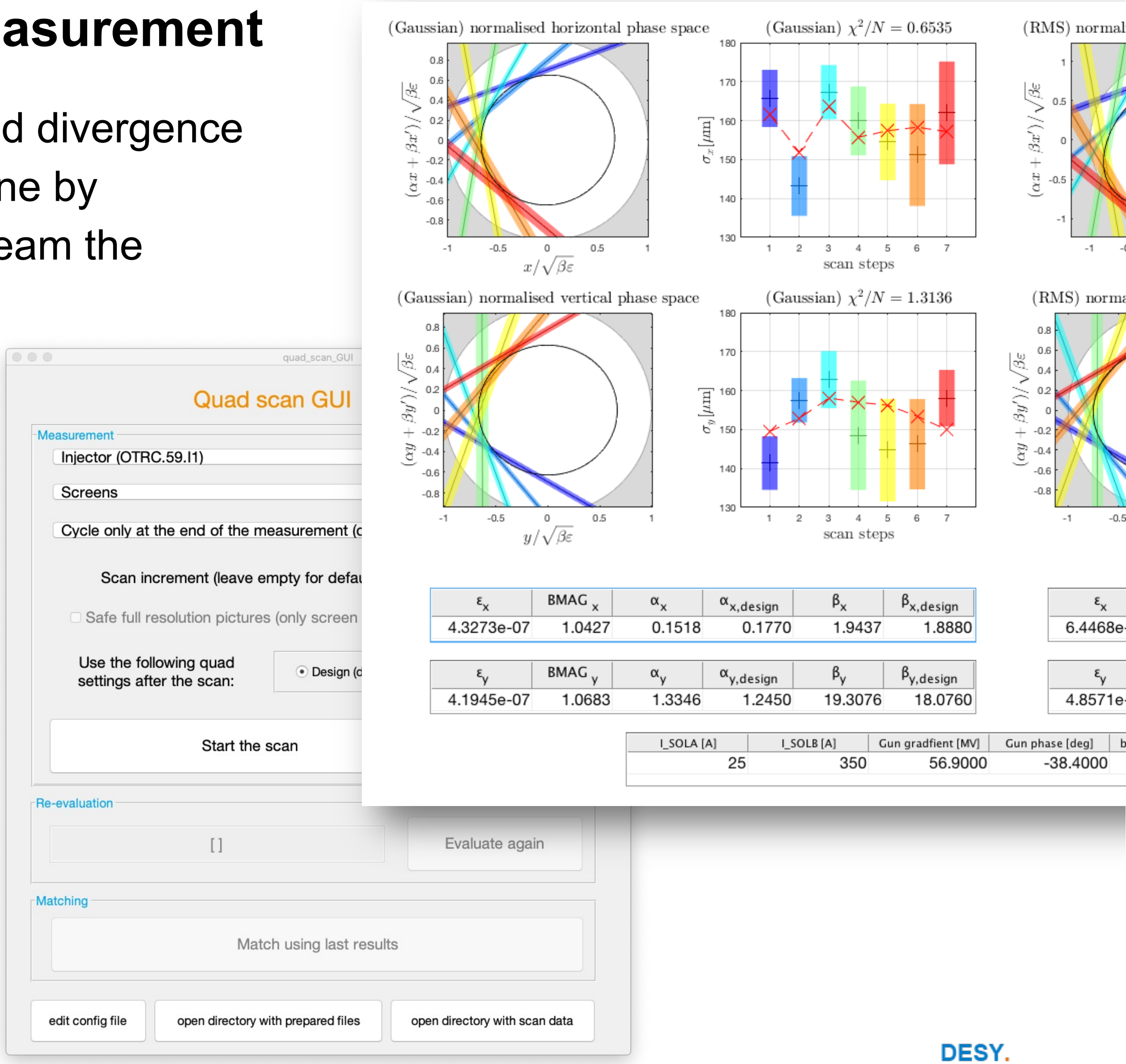
Laser on the cathode

- Checking the injector laser spot on the virtual cathode to ensure that the shape and homogeneity are ok.
- QE map of the cathode.
- Adjust the laser’s position feedback such that the laser hits the correct spot on the cathode.



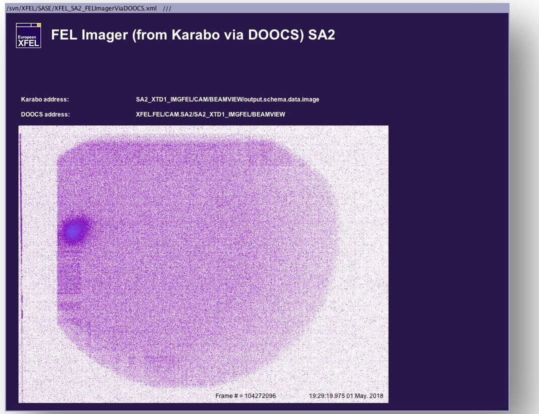
Beam optics matching and emittance measurement

- Matching means to bring the electron beam’s size and divergence into line with the design optics of EuXFEL. This is done by changing the strengths of quadrupole magnets upstream the measurement point.
- This measurement can be done in different ways. We use multi quad scans that have a high error tolerance.
- The emittances are measured in the same way.
- There is a tool available for measurement and matching that can be used by all operators.
- Depending on the starting conditions, we need 2-3 matching iterations.



Injector dispersion

- We learned rather early that the general performance is very sensitive to the trajectory in the injector.



First lasing on 1. May 2028

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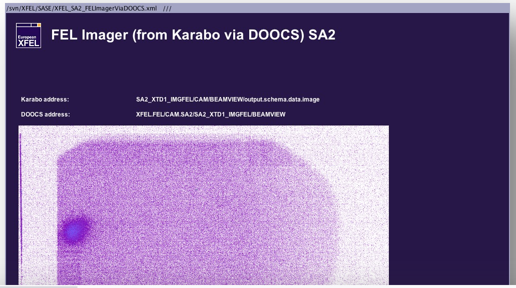

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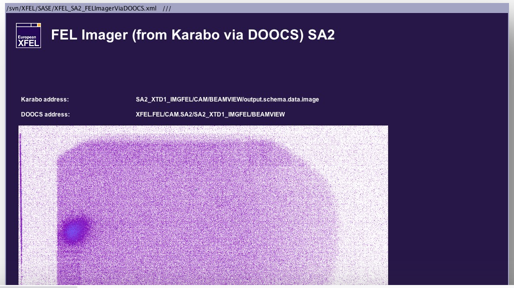

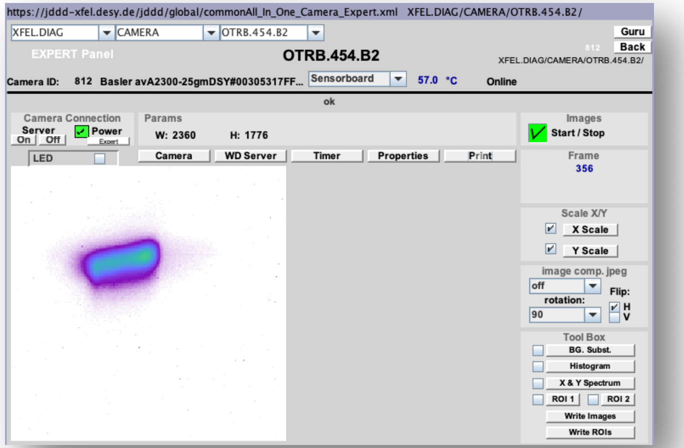

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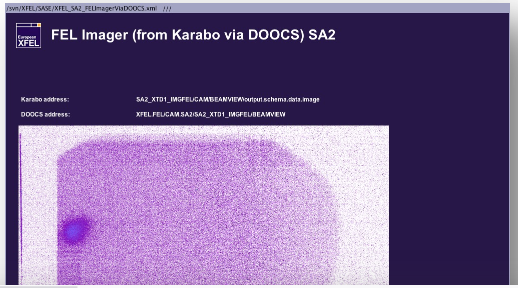
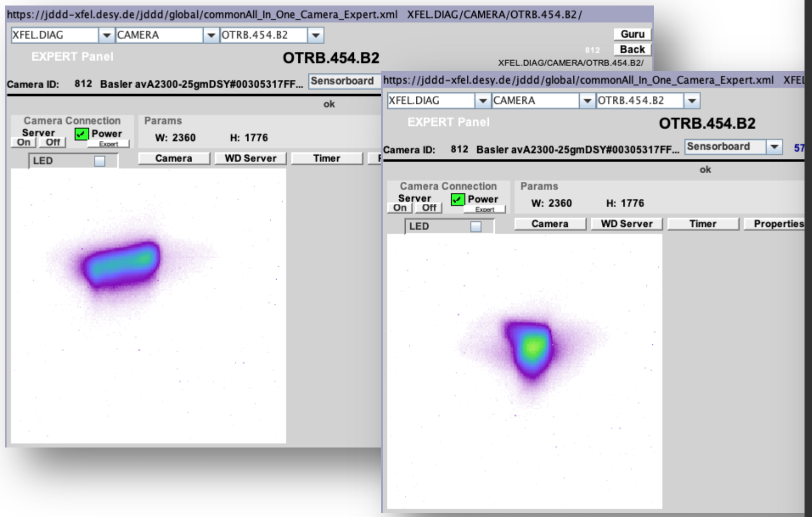
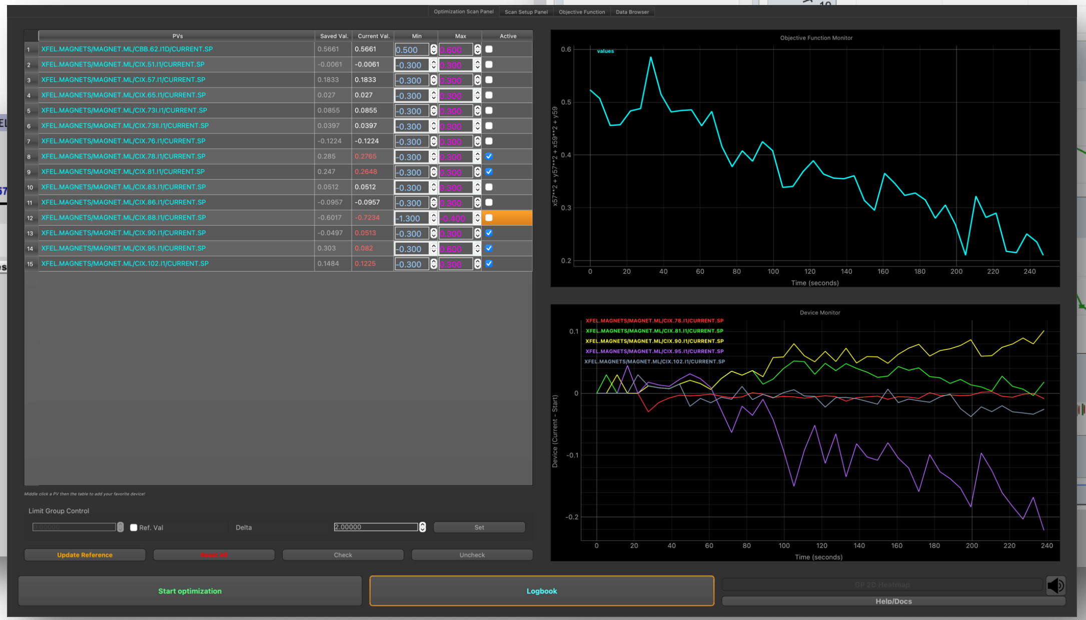
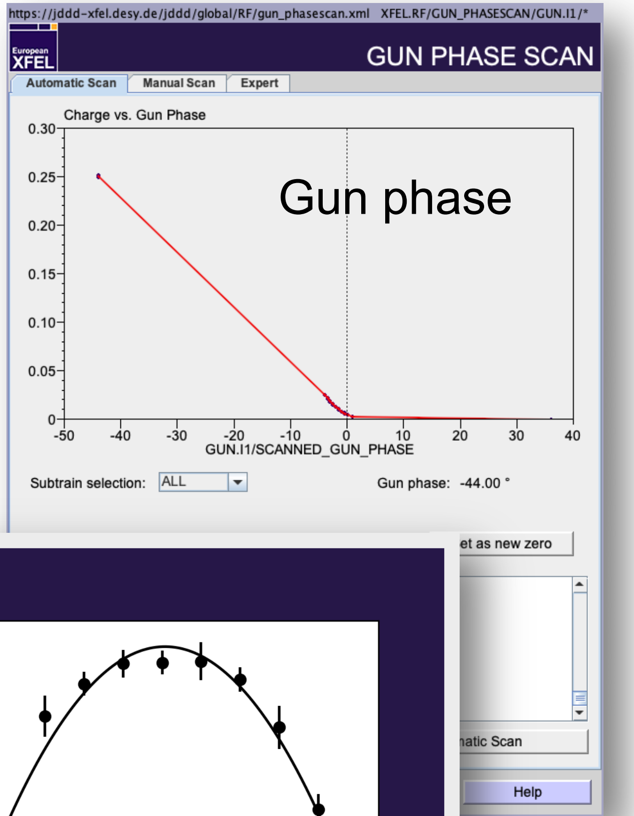


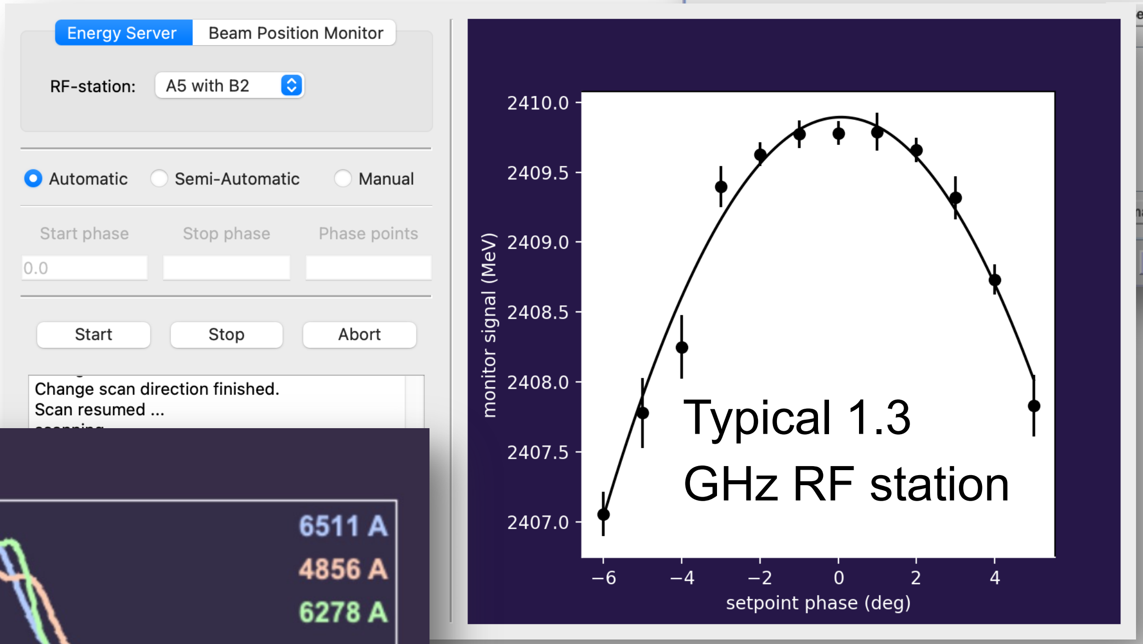


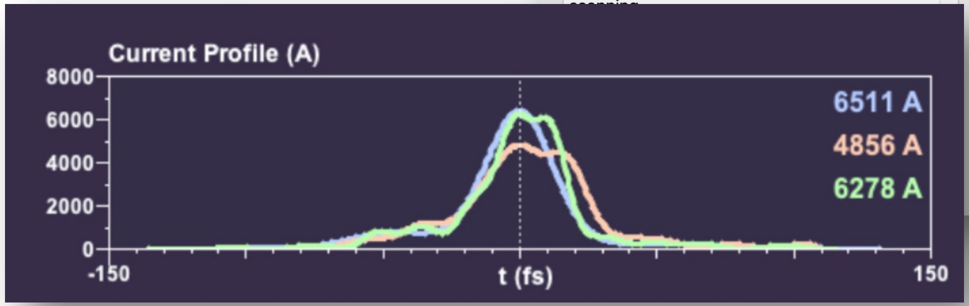


RF on-crest phase measurements

- All RF on-crest phases have to be measured in order to allow a proper bunch compression setup.
- Most important are the gun and the RF stations A1-A5 plus AH1 (all stations upstream the bunch compressors).
- The on-crest phases of the RF stations in L3 (A6-A24) can be measured parasitically.
- This is followed by the bunch compression setup. Typically, we start with our design values for energy chirp, curvature and cubic coefficient.

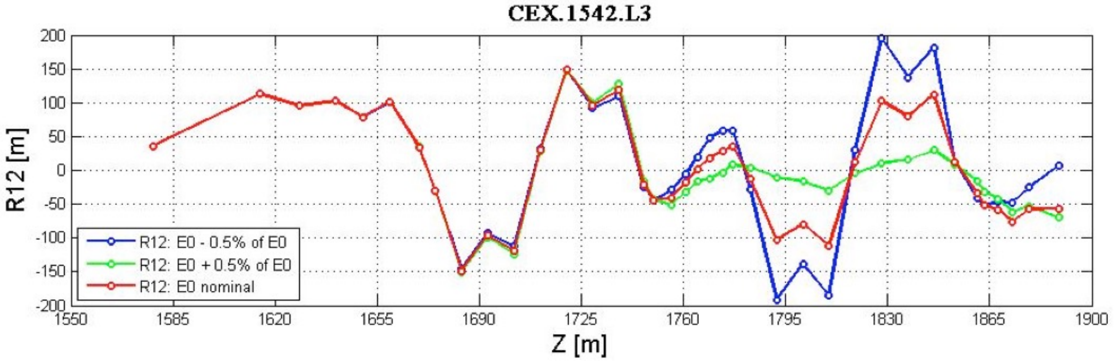




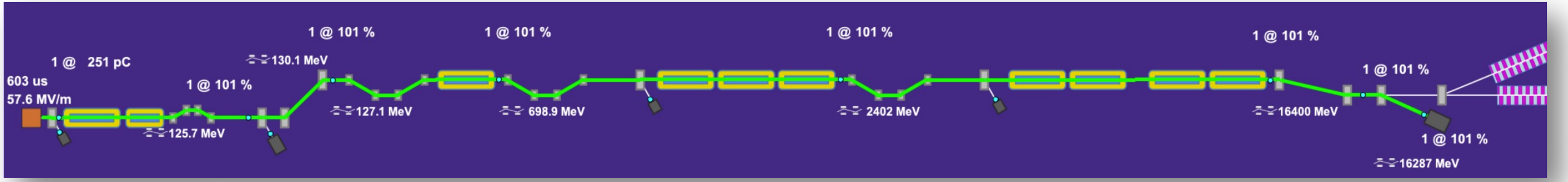


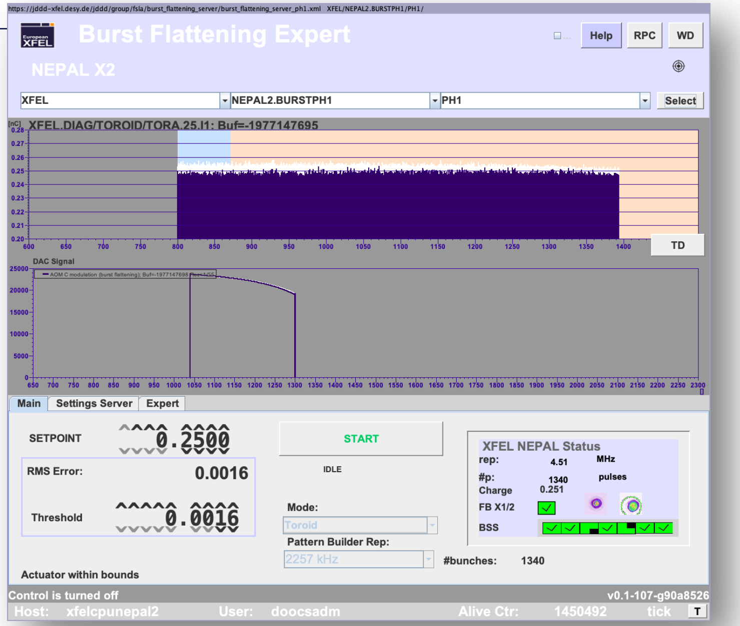
Beam transport to TLD

- The beam’s response to a horizontal kick upstream the collimations section is very sensitive to the correct setup of the electron beam energy (~0.1% -> 10-20 MeV).
  - This fact is use as a very precise measurement of the electron beam energy downstream L3.
  - However, we typically observer a small positive photon energy offset in all three beamlines.



- As soon as a dispersion and loss optimized trajectory to TLD is established, we switch to long bunch trains.
  - Typically, ~2.25 MHz repetition rate -> 1350 bunches in 600 us.
  - Check dump temperatures

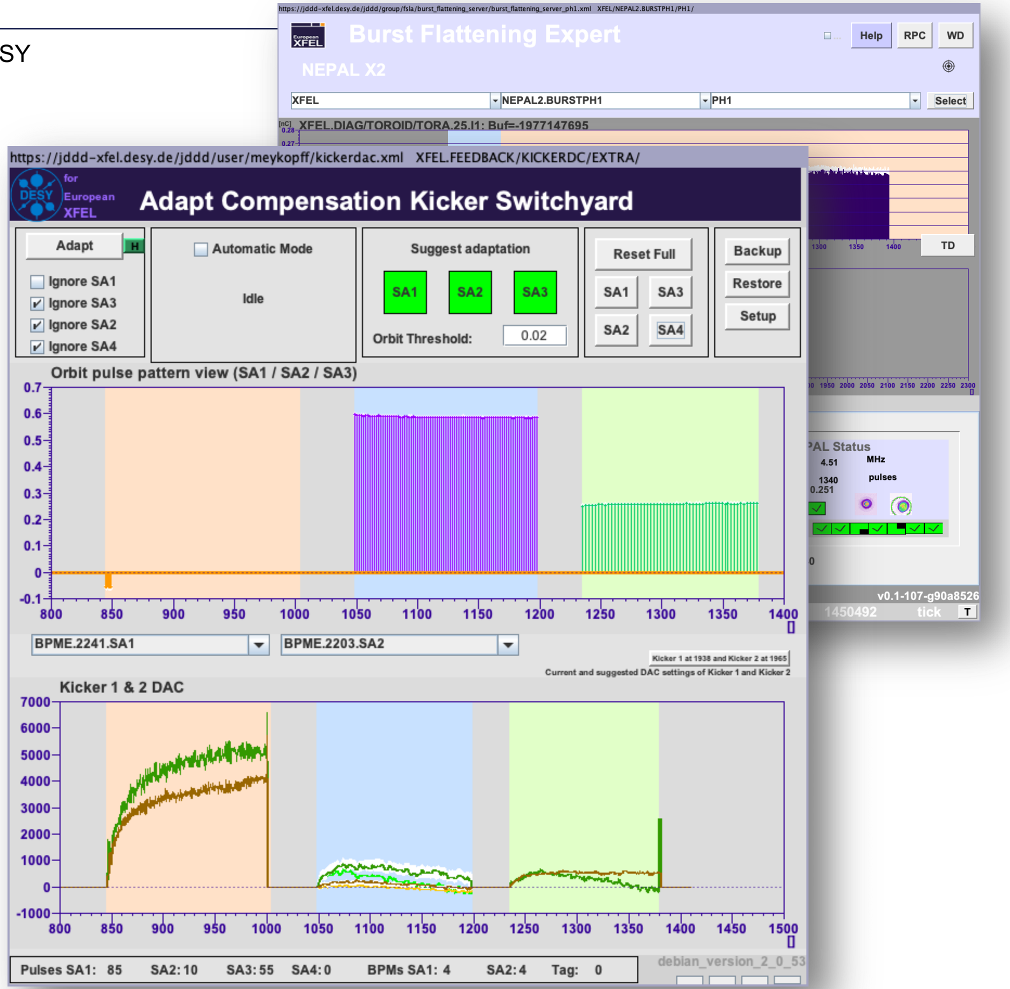




Long pulse trains

- Ensure that all bunches have the same charge over the pulse train.
- Apply the correct pulse forms to the adaption kickers that ensure the same trajectory of all bunches.
- Check the status of the IBFB.
- The bunch train energy FB ensures that all bunches have the same energy at the end of the main linac.
- Prepare the fast longitudinal feedback.

Long pulse trains



- Ensure that all bunches have the same charge over the pulse train.
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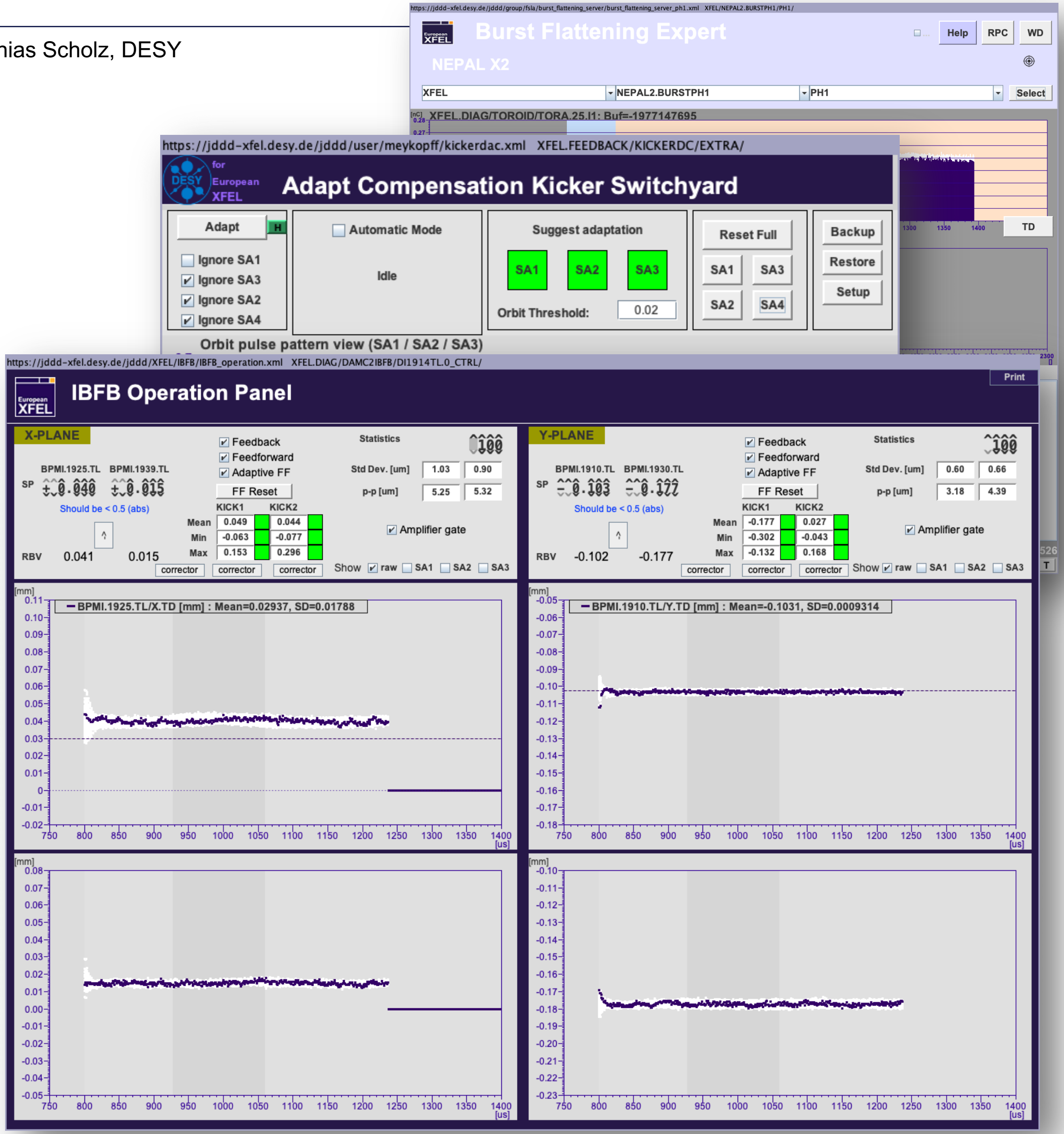

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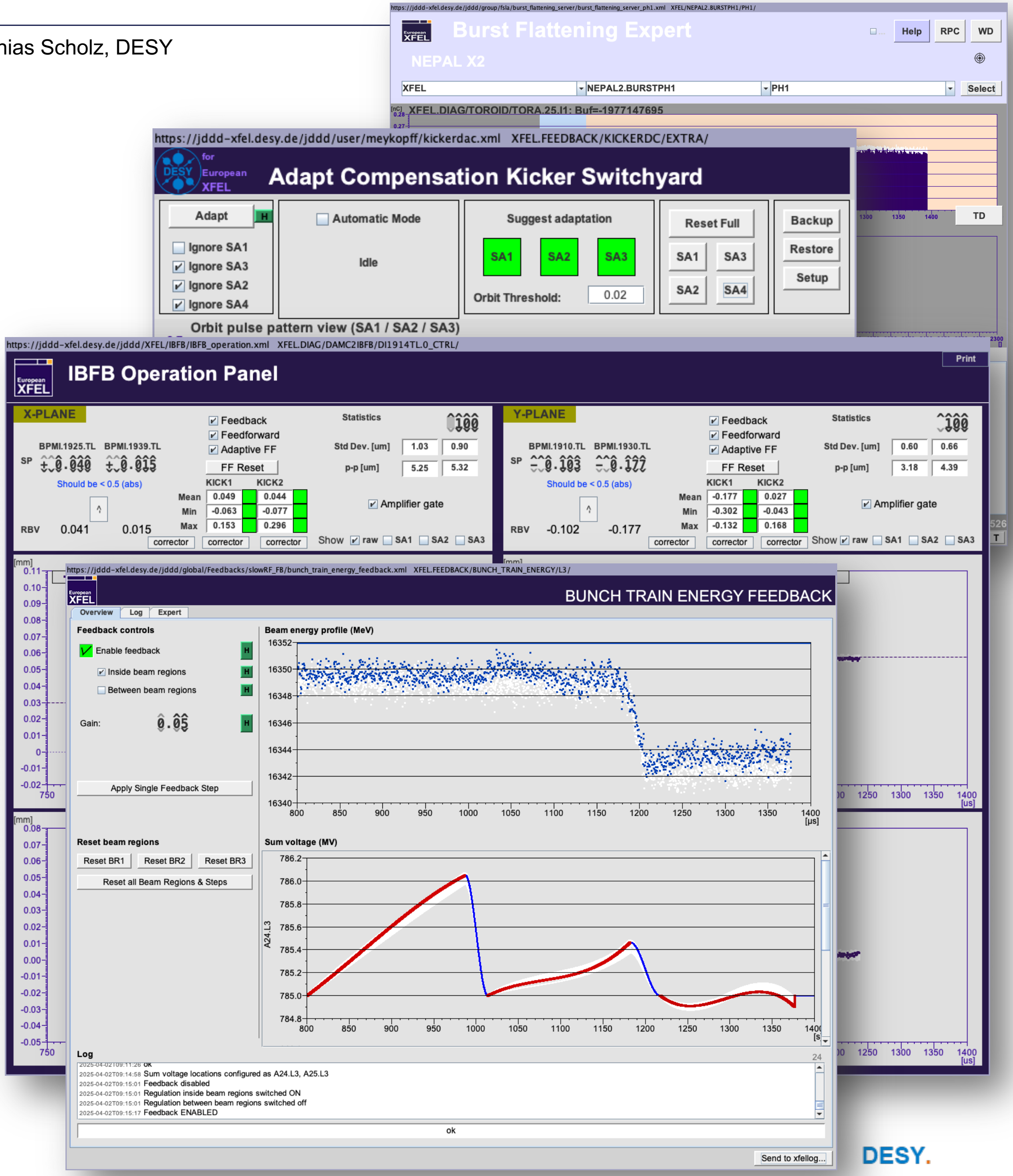
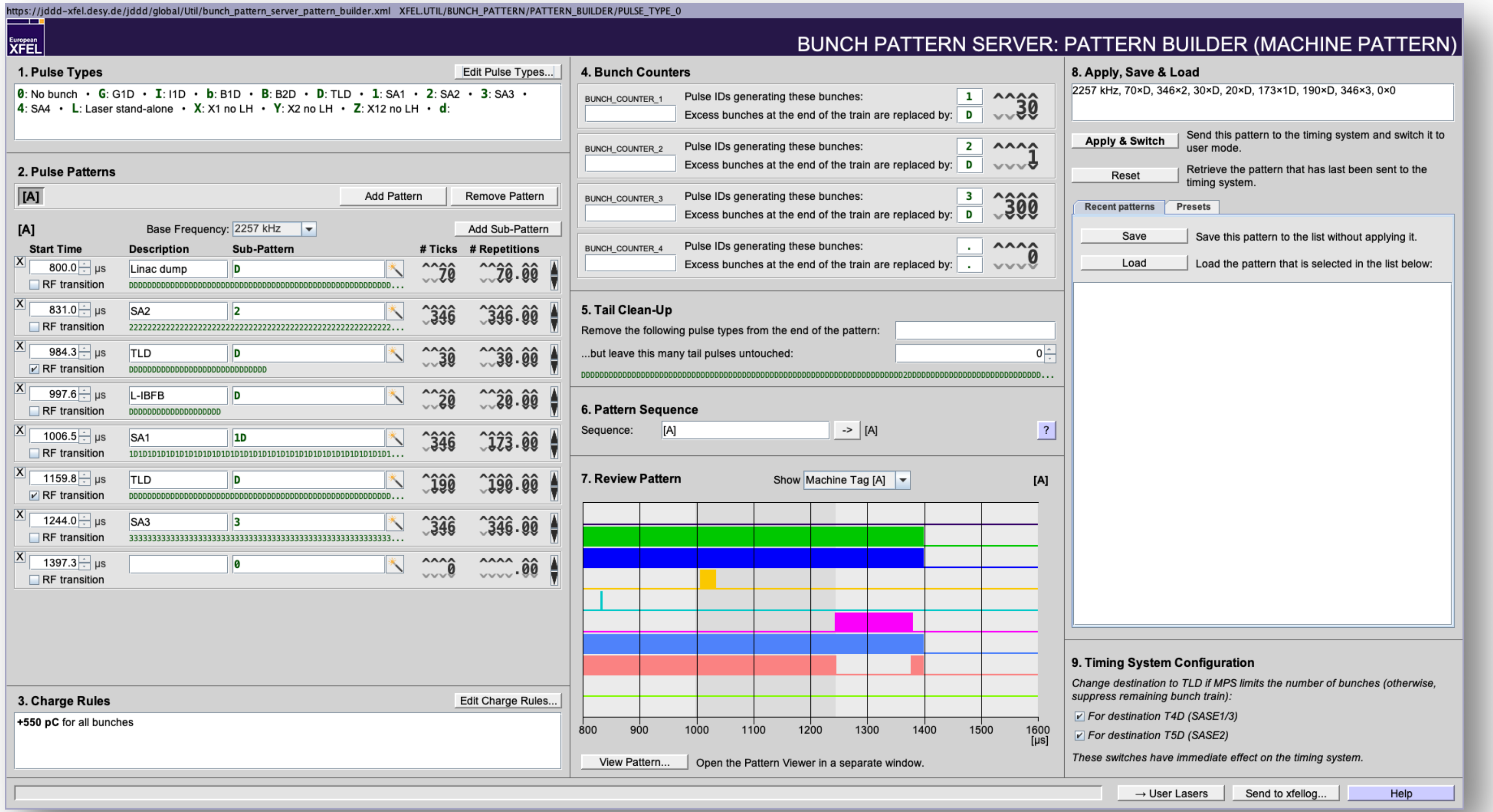


Beam to north and south branches

- Beam distribution to all undulator beamlines.
- Bunch pattern setup.
- Undulator preparation for the requested photon energies for the coming week.
- Depending on the previous changes on the lattice, first SASE signals can be found quickly.
- Tuning of the standard operation modes can start.



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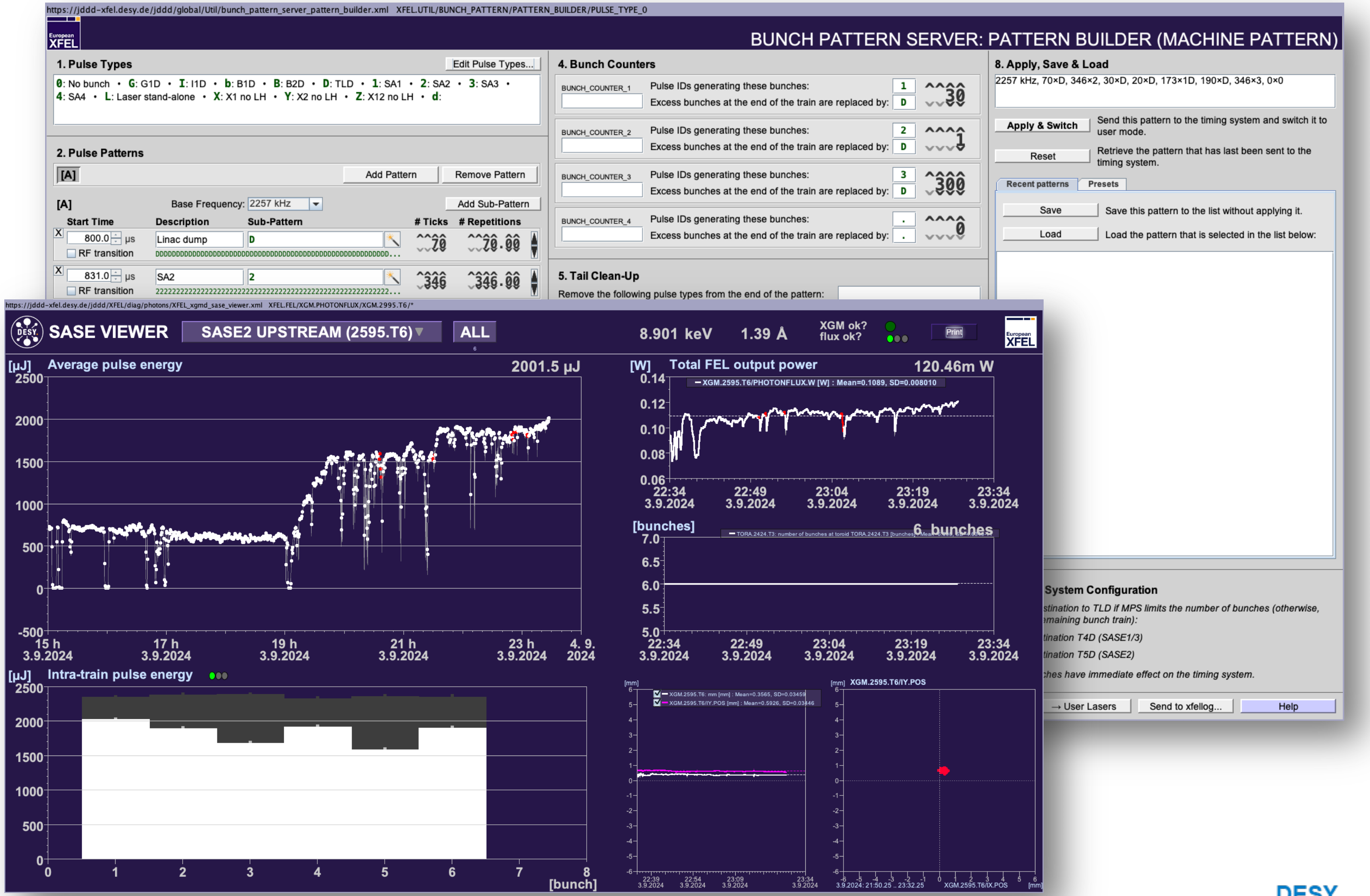

A few words on electron beam based alignment eBBA

- We have recently carried out eBBA twice a year for all three beamlines.
- eBBA ensures the correct position of the quadrupole magnets in the undulator beamlines with a precision of <10 um.
- Idea of eBBA: Steer electron beams with different energies (6, 8, 12 and 17.5 GeV) through the undulator beamlines while keeping the quad-currents the same (this changes the relative kick strength).
- Preparation time (all beamlines): about 4-8 hours. The same is true for the eBBA itself.
- eBBA has it weaknesses towards the end of the undulator beamlines because we have less and less BPMs available downstream to track the trajectory of the beam.

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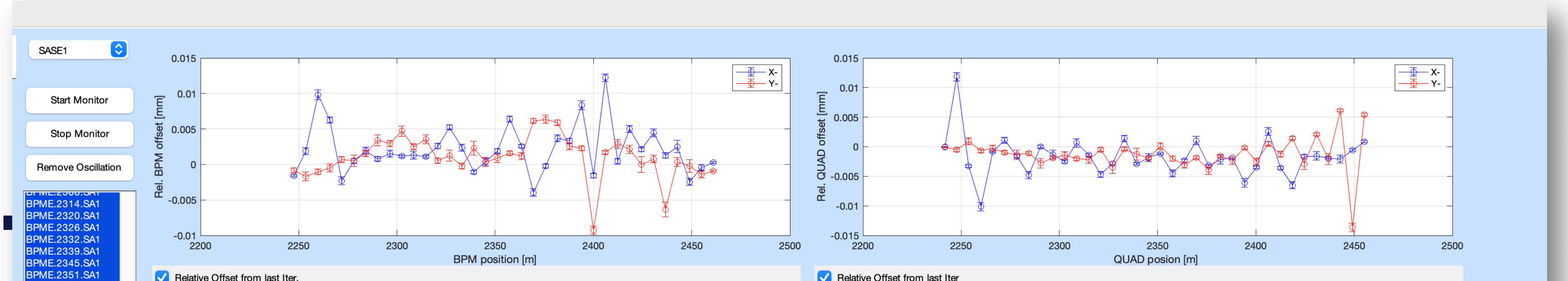
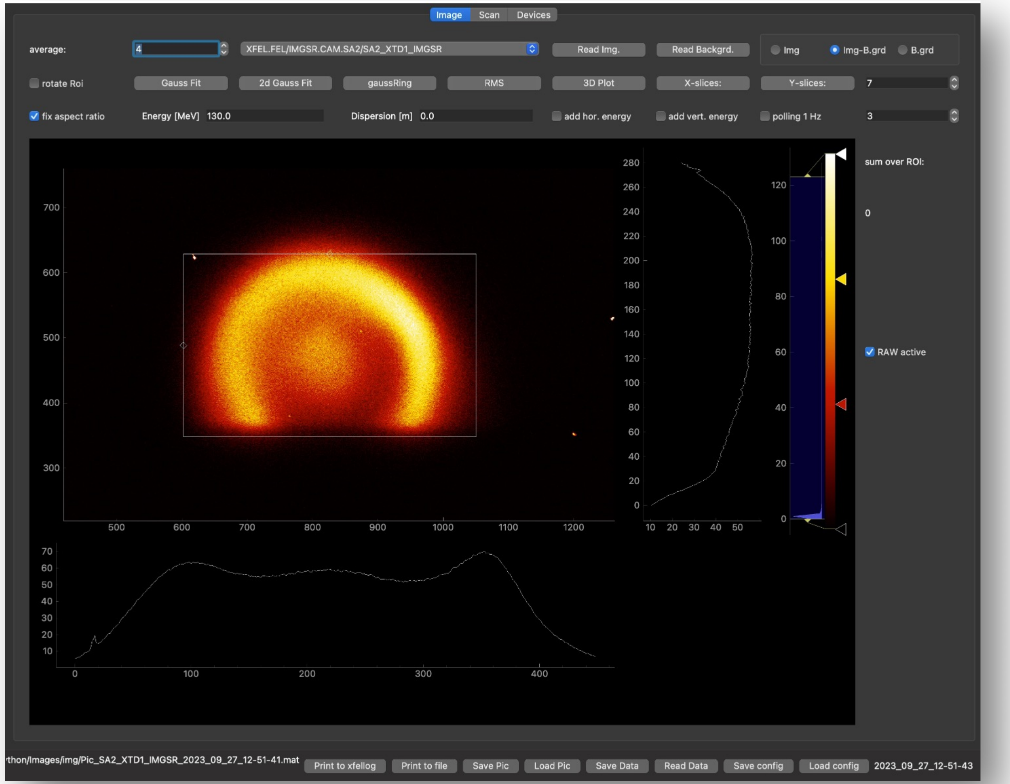
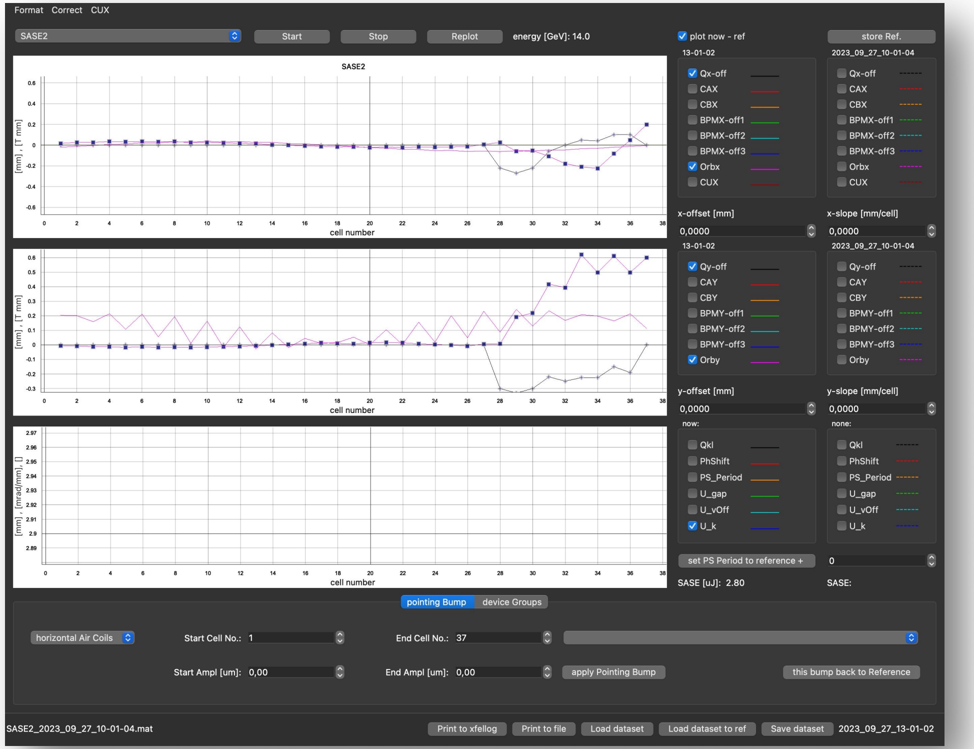


Photon beam based alignment pBBA

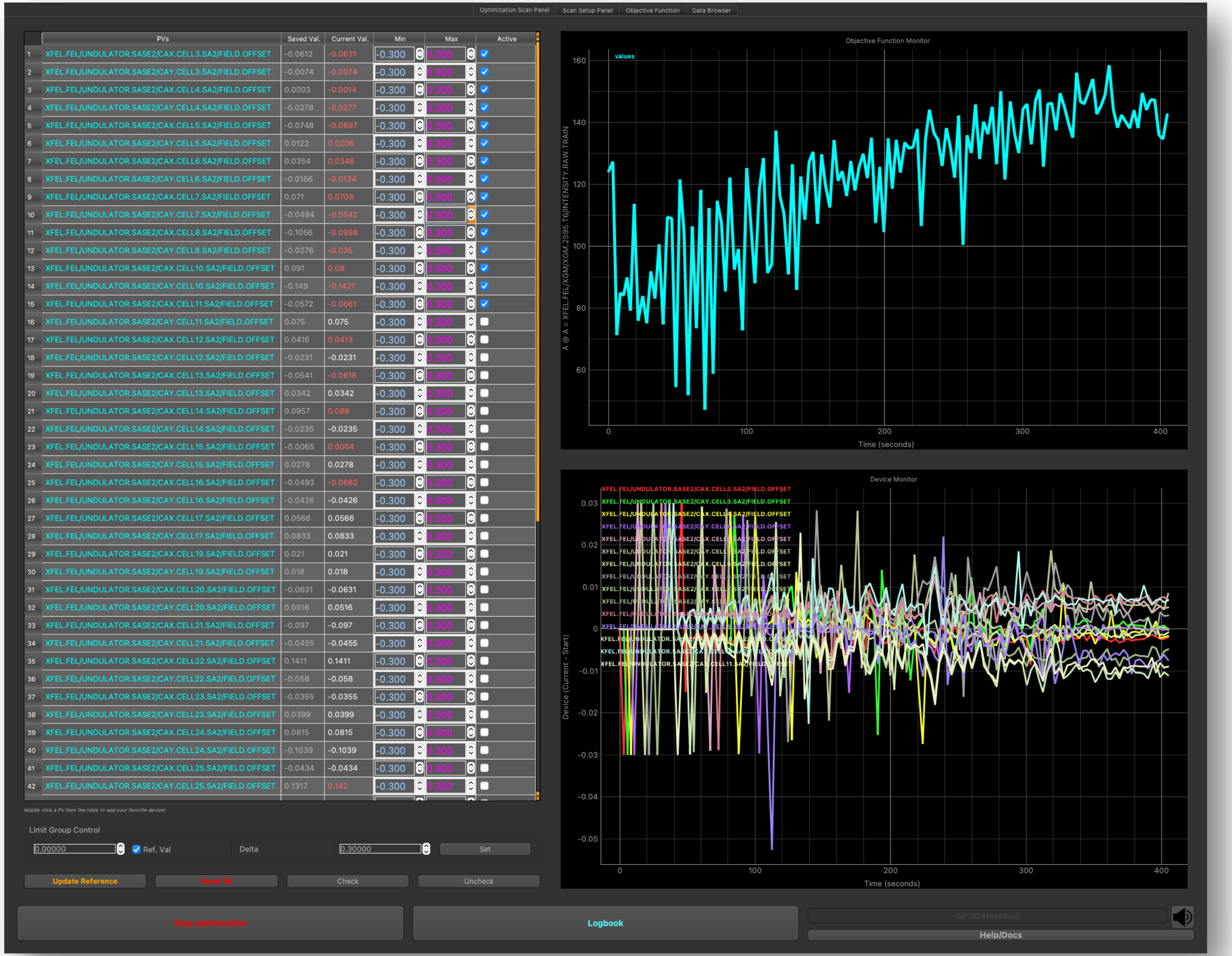
- Using K-Mono to align individual undulator cells one by one.
- Very helpful to correct the last 30% of the undulators that are not perfectly aligned after the eBBA.
- Time required for that: about 1-2 hours per undulator.





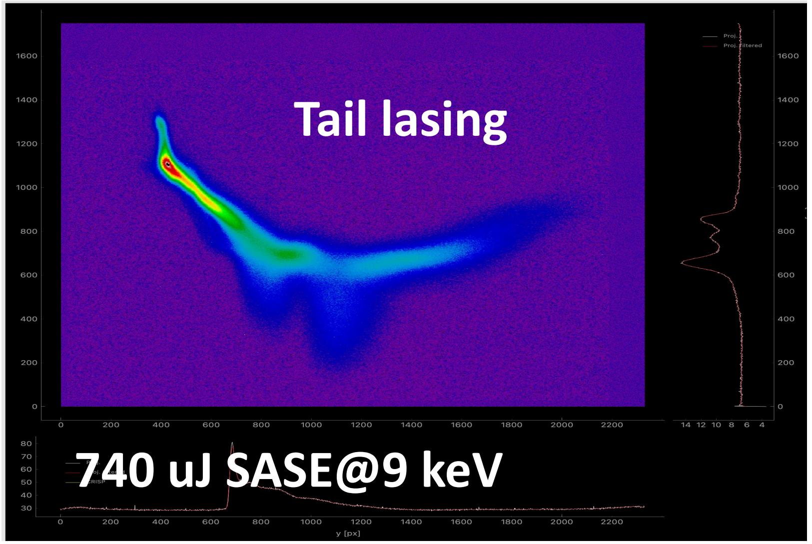
SASE tuning

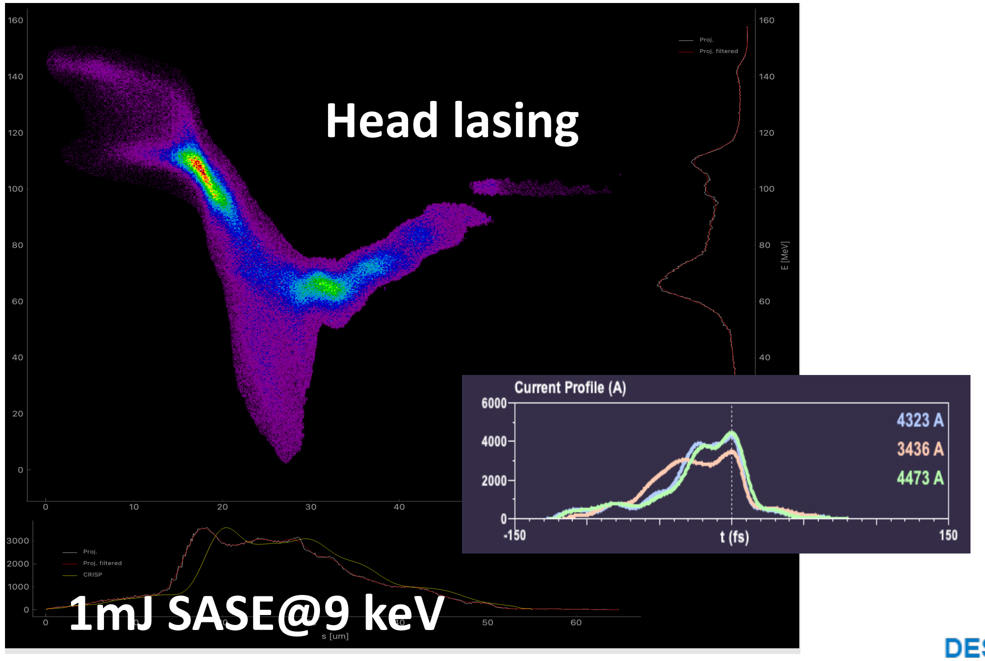
- Trajectory inside the undulator
- Beam optics
- Tapering
- Compression
- Phase shifters
- ‘common knobs’ in the linac.
- Main Tool: The Ocelot Optimizer and the Phase Shifter Scan.



SASE tuning, longitudinal phase space

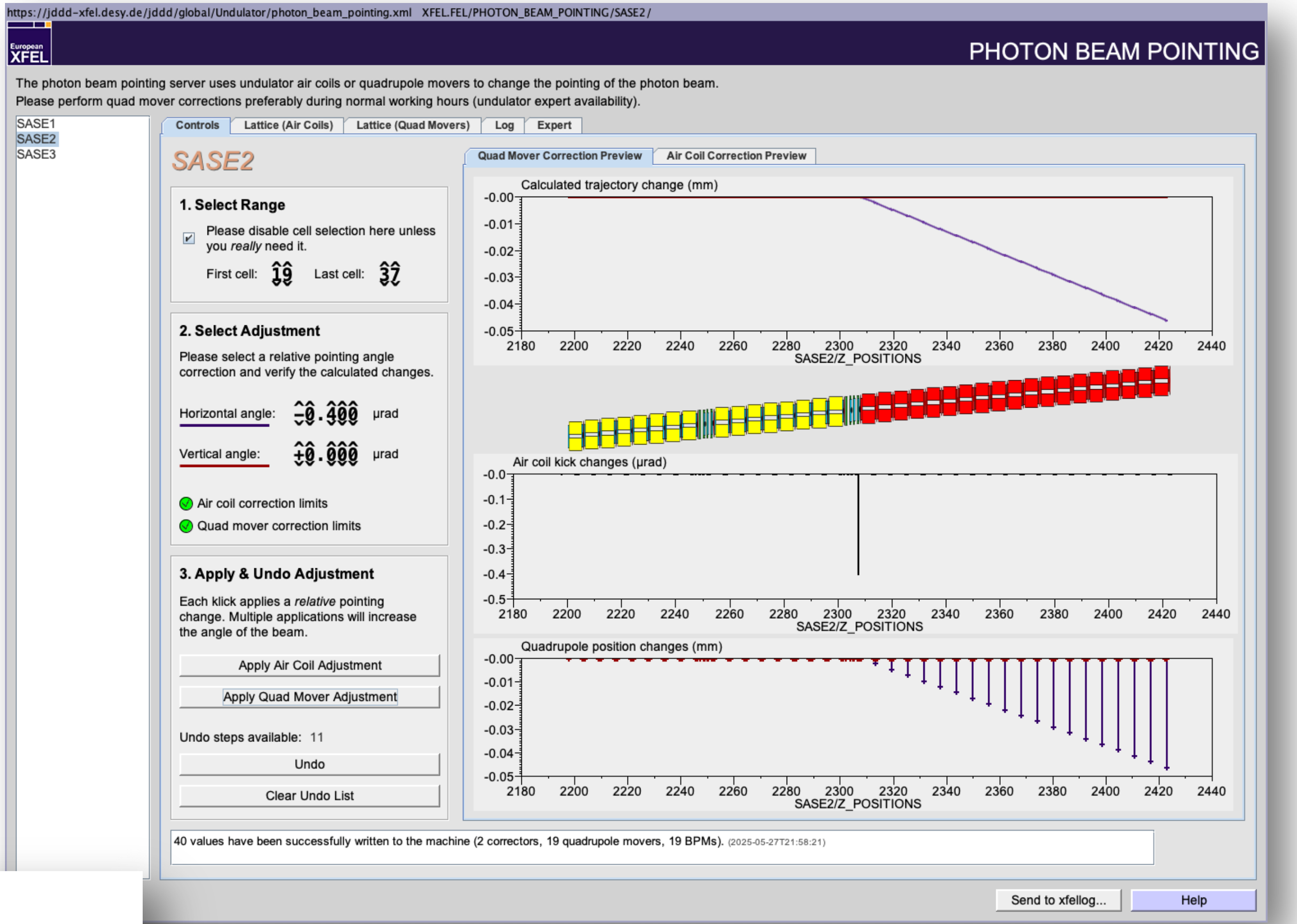
- Corrugated structures will be available in both branches in 2026.
- We've learned how to use them effectively for compression tuning in order to improve performance.

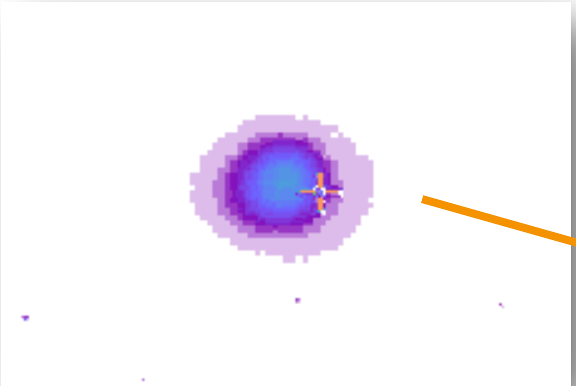


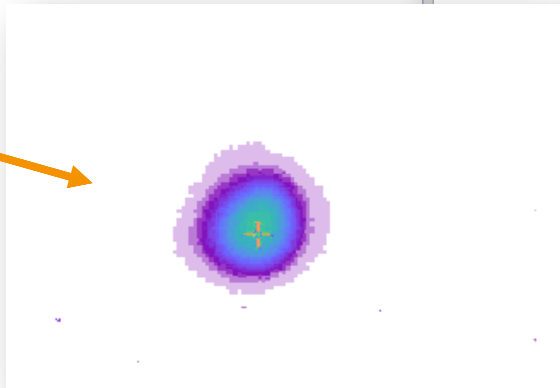


Last but not least: Pointing

- The photon beam pointing server is used to get the photon beams on the respective crosses.
- This tool changes the angle of the straight line that was found with BBA and tuning.
- It can also move only parts of the undulator.





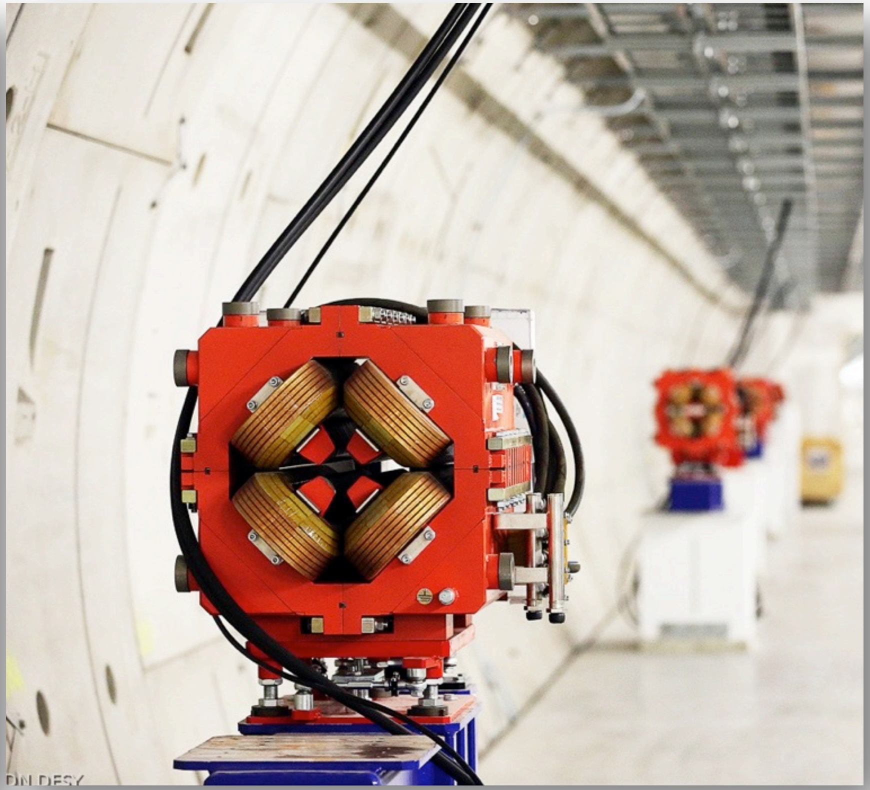
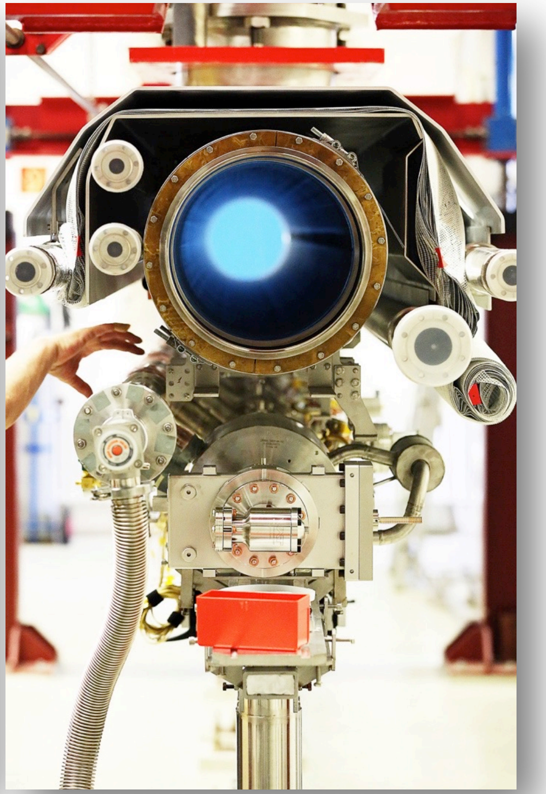


Typical tuning schedule

- Tuesday:
  - Setup day for Standard Operation Modes
  - Accesses for maintenance and repair if necessary.
  - Typically, the major tuning effort is done around midnight.
- Wednesday
  - 7am: Start delivery of Standard Operation Modes
  - Setup of Non-Standard Modes

- Preparation of all photon energies and other setups requested for the week are prepared beforehand.
- Switching photon energies, pulse patterns etc. is highly automated and can be done by the operators.
- -> We are working on improving automation in order to make setup and operation more reproducible and less dependent on experts -> Frank's talk this afternoon.



Thank you for your attention