Undulator trajectory alignment

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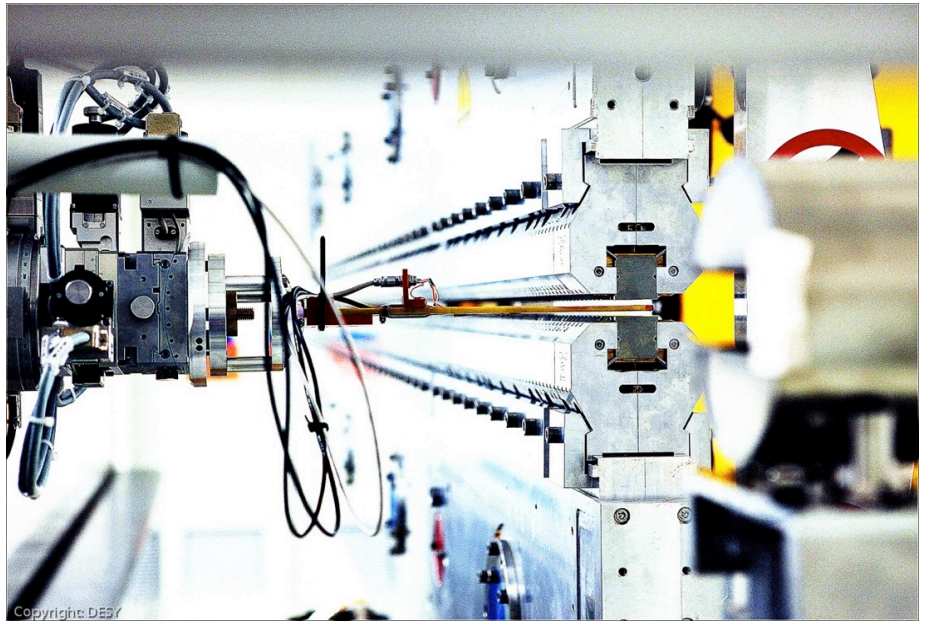
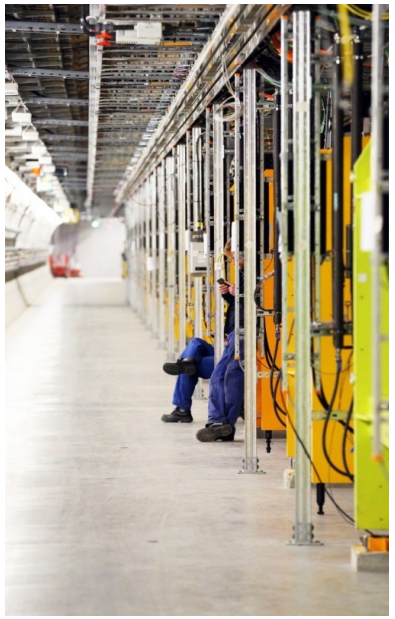
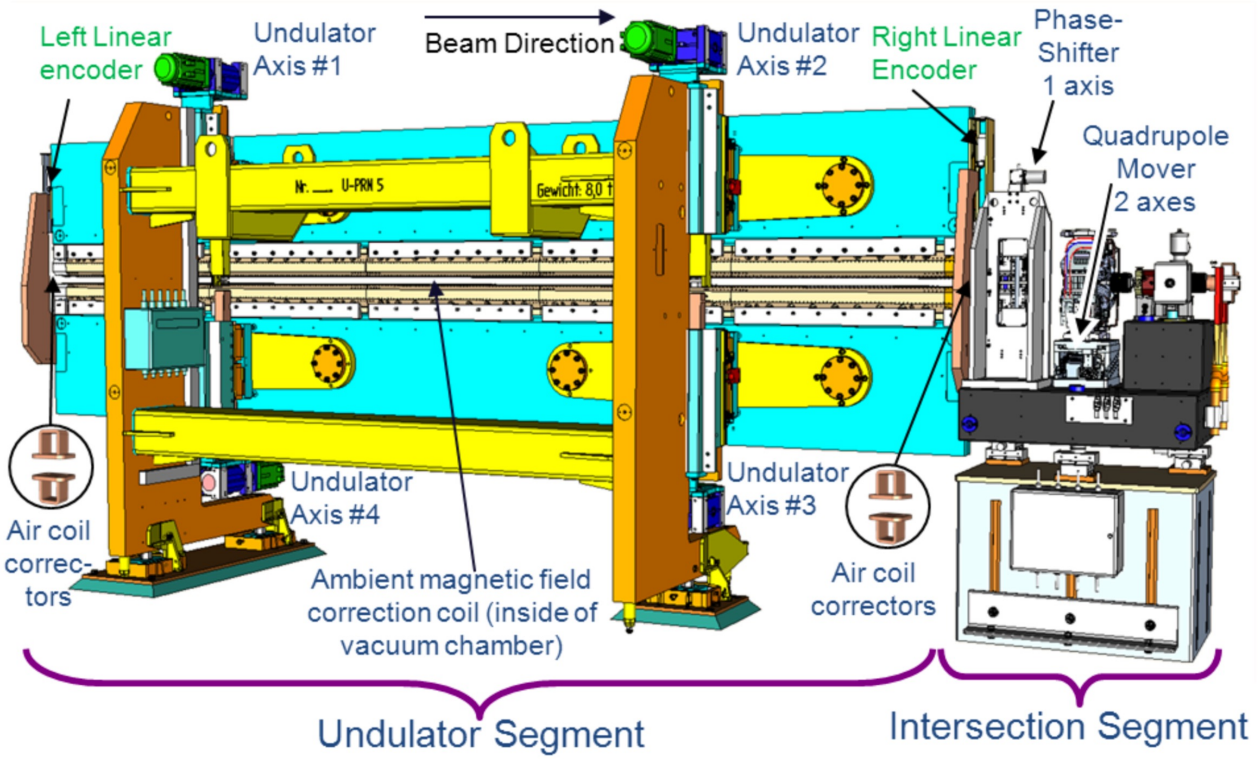
Hamburg, April 30, 2025





Undulator cell

An undulator cell of 5 meter length with 2 pairs of air coils at both ends. Max gap: 220 mm, minimum gap: 10.5 mm.
SA2: 37 cells installed -> 27 * 6.1 m = **225.7 m** (incl. chicanes).



Intersection (1.1 m) with phase shifter, quadrupole magnet on mover (2 axes) and beam position monitor.
The phase shifters are build with permanent magnets and variable gaps.

Start of the alignment: Electron beam based alignment

Methode

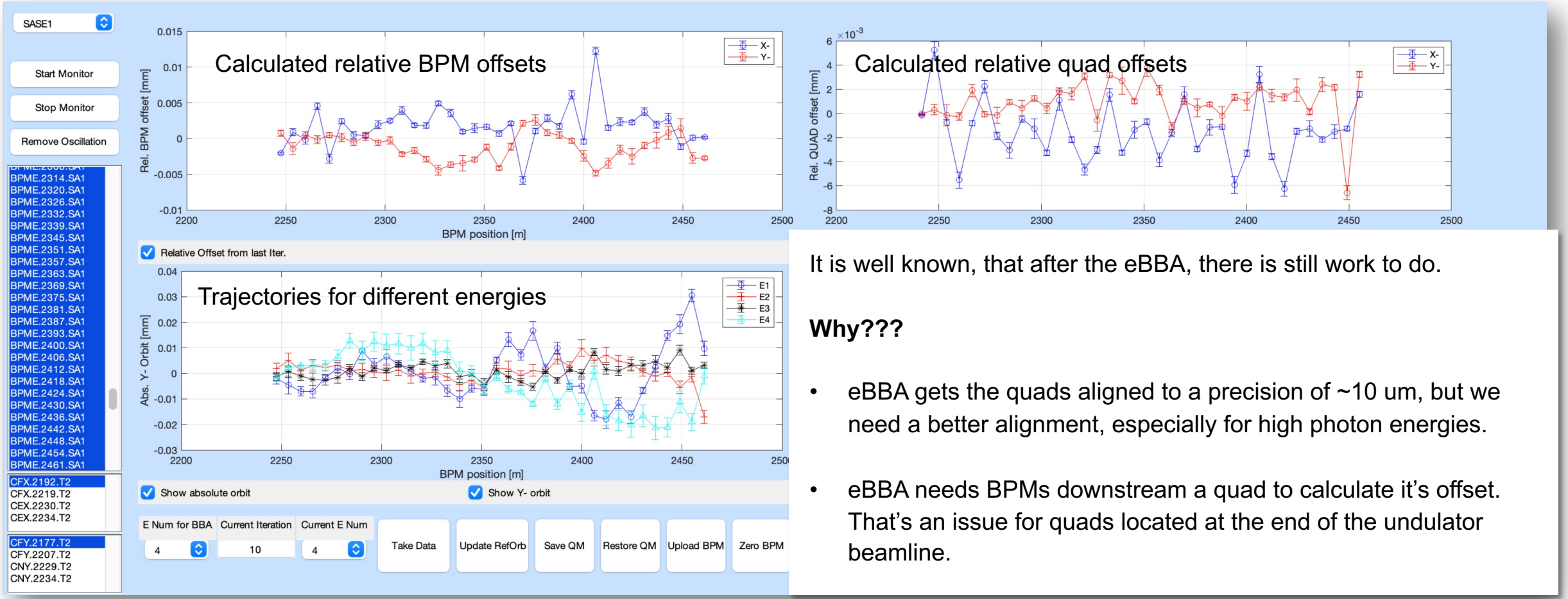
- Electron Beam Based Alignment (eBBA)
  - Electron beams with different energies (6, 8, 12 and 17 GeV) are sent through the undulator beamline one after another.
  - Trajectories are measured in the undulator beamlines for each beam energy.
  - An algorithm calculates the offsets of the quads and the BPMs and provides correction values.
  - Typically, we need 5-15 iterations (each with the 4 beam energies).
  - File Preparation and BBA in all beamlines can take between 1 and 2 shifts.

- How does it work
  - Quadrupole currents are the same all the time -> effective kicks from the quads change.
  - Quads with an offsets kick the beam. Quad kicks **depend** on the beam energy.
  - BPM offsets do **not depend** on beam energy.
  - This is how we can distinguish offsets from quads and from BPMs.

At the end of the eBBA, we measure a perfectly straight line through all BPMs. The quads are not completely steering free (as often assumed) but the kicks from the quads perfectly correct the impact of ambient fields on the bunches' trajectory.

The trajectories of the 4 different beam energies overlap perfectly. -> The end of the eBBA

eBBA example SA1, last iteration



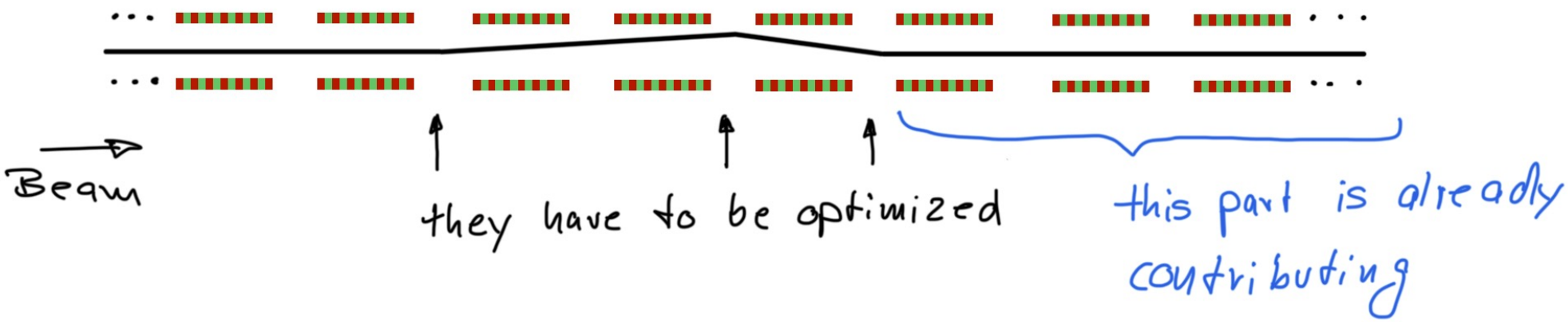
It is well known, that after the eBBA, there is still work to do.

Why???

- eBBA gets the quads aligned to a precision of ~10 um, but we need a better alignment, especially for high photon energies.
- eBBA needs BPMs downstream a quad to calculate it's offset. That's an issue for quads located at the end of the undulator beamline.

Next step: air coil alignment. How to start

- Reason 1, why you should start with a minimum number of closed undulator cells



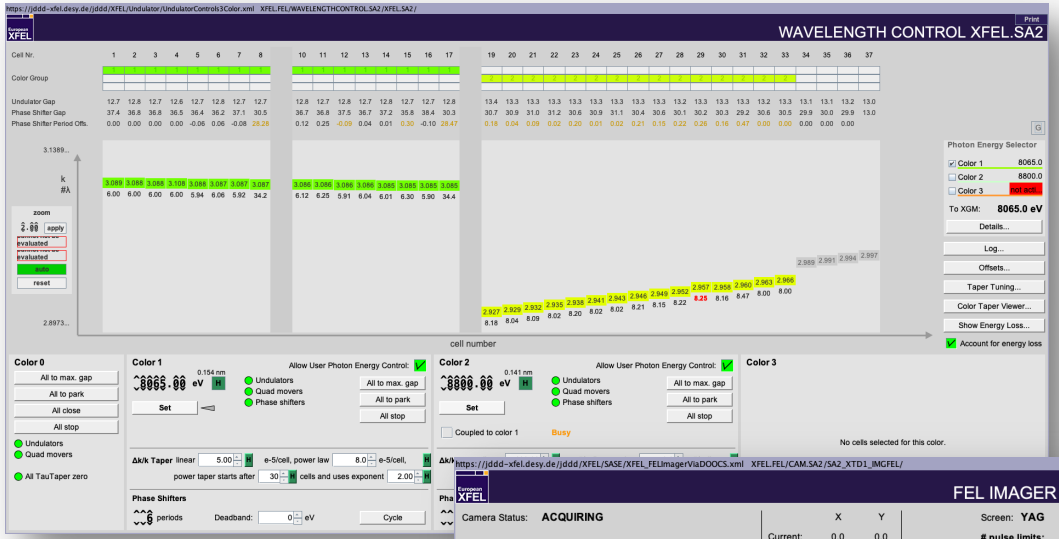
- The less cells are closed, the less aircoils have to be part of your optimization.
- Since the Simplex algorithm used in the optimizer is limited to ~8 actuators at the time, it makes sense to reduce the number of cells involved.
- In the situation above, it can happen that you get the first problematic cell in line, but you misalign all the cells downstream -> pulse energy goes down and you will not see the improvement of the first cell. This is a very common problem.
- This is not a problem, when the downstream cells are open. The minimum pulse energy should be around 100 uJ.

Next step: air coil alignment. How to start

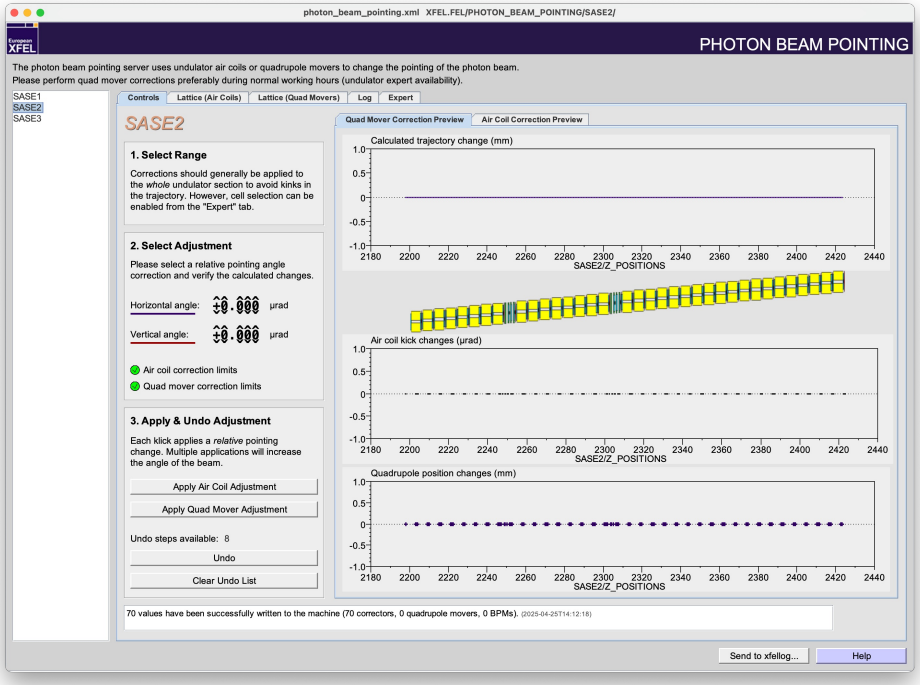
- Reason 2, why you should start with a minimum number of closed undulator cells

- Optimizing all undulator cells is even more complicated if you have so many cells closed, that you run already with a power taper.
- Let's say the power taper starts at cell 18, which is the best setting you found with 3 cells misaligned upstream (that you don't know about yet).
- It means would you have to adjust the start of the power taper by -1 at the very moment when one of the upstream cell gets aligned. Otherwise, the taper is wrong and, in spite of the additional aligned cell, the pulse energy might drop -> you will not align the cell.
- This is actually also a problem for other tuning attempts. E.g. quad optimizations upstream the undulator (should) reduce the gain length and require thus an earlier start of the power taper. If that is not adjusted accordingly, you might not find the possible improvement.
- Solution: less cells at a time. And if you want/need to have so many cells closed, check every now and then whether you can reduce the start of the power taper. This gives you some headroom for further tuning steps.

Check the beam pointing



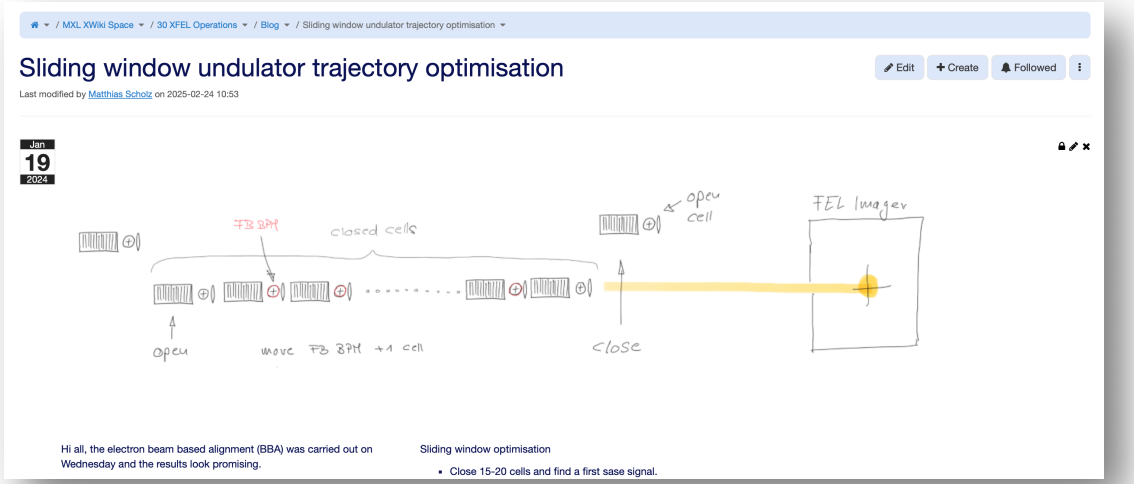
Screenshots from
February 12, 2025

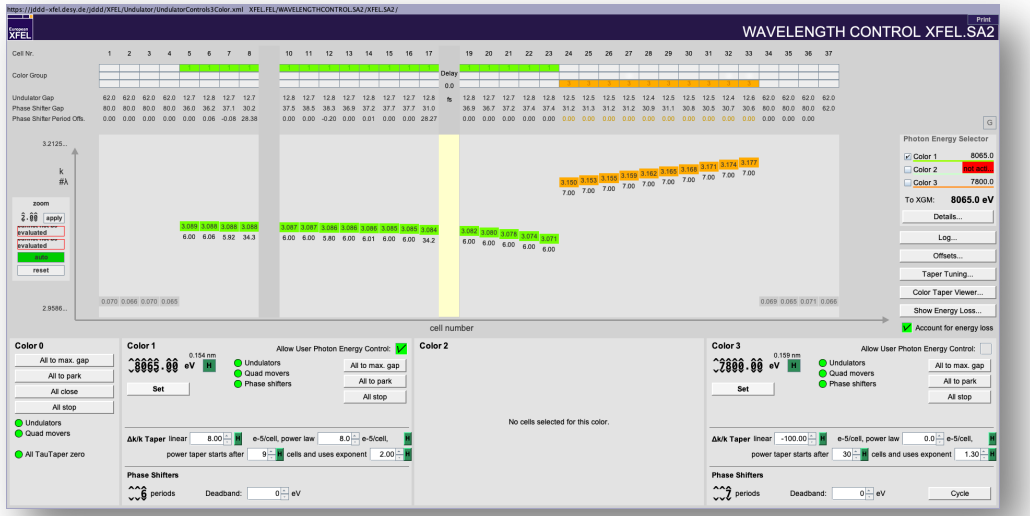


- Check the photon beam pointing in time, not only after the final tuning.
- For pointing corrections, use the Photon Beam Pointing server shown above.
- At this time, pointing corrections should be carried out with quad movers not with air coils!
- Depending on the photon energy, it might be necessary to do some small air coil optimizations after a pointing correction.
- It is possible to achieve the same pulse energy again as before the pointing correction!

Sliding window optimization

- Sliding window optimization means that cells at the beginning of the undulator are opened and others at the end are closed.
- The pulse energy and pointing should be the same for all combinations of cells.
- Doing this cell by cell is tedious and, in most cases, not necessary. A 3-step approach (first cells, middle cells, last cells) does the trick at most times.
- This helps especially for seeding, since it can be guarantied that the last cells are well aligned.





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- Blog entry on SWO https://xwiki.desy.de/xwiki/short/539c6

No contribution from last cells

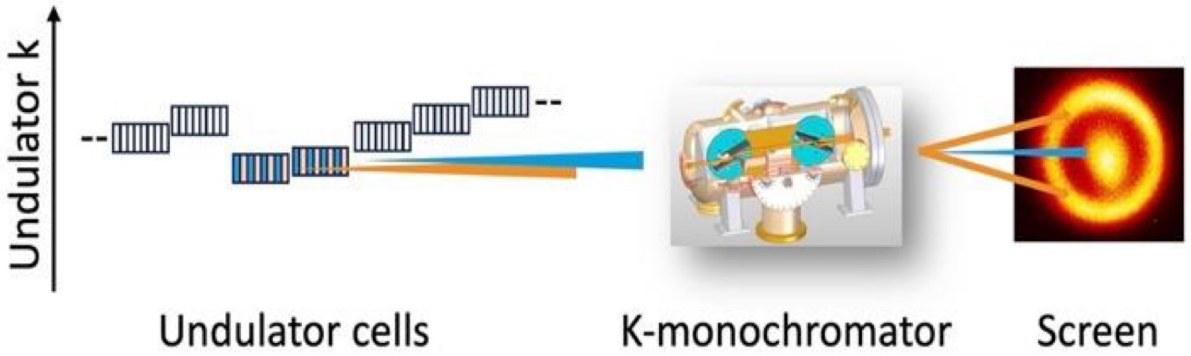
FEL23 conference proceedings

- As said on slide 4, it can be that the cells are not well aligned after eBBA -> k-mono and the pBBA the photon Beam Based Alignment can help.
- First time applied for alignment in September 2023: Logbook
- More info about the k-mono on XWiki (can be also found under procedures).

- So far, k-mono can only be operated via Karabo and can easily be damaged, thus no manual how to start it here.
- This device allows us to study the pointing of individual undulator cell one-by-one.
- Typically, we check the pointing of some lasing cells and adjust the other cells to the same point.
- A few more things have to be considered, but in general that works out nicely.

2nd step: Photon Based Alignment of single undulator pointing

- Pointing of spontaneous radiation compared one by one and adjusted with air coils



$$\lambda_{mono} = \lambda_p \frac{1}{\gamma^2 2n}\left(1 + \frac{1}{2}K_{eff}^2 + \gamma^2\theta^2\right)$$

- An alignment of the last 10-15 cells of SA1 or SA2 takes about 1 h including all preparations.
- Automation will follow.
- The result is good enough to find overlap/contribution but some fine tuning is still needed (air coil optimizations).

News

- XWiki access permissions
- MPS panel and magnets on spare power supplies

- Phase shifter kicks
  - What is the best setup