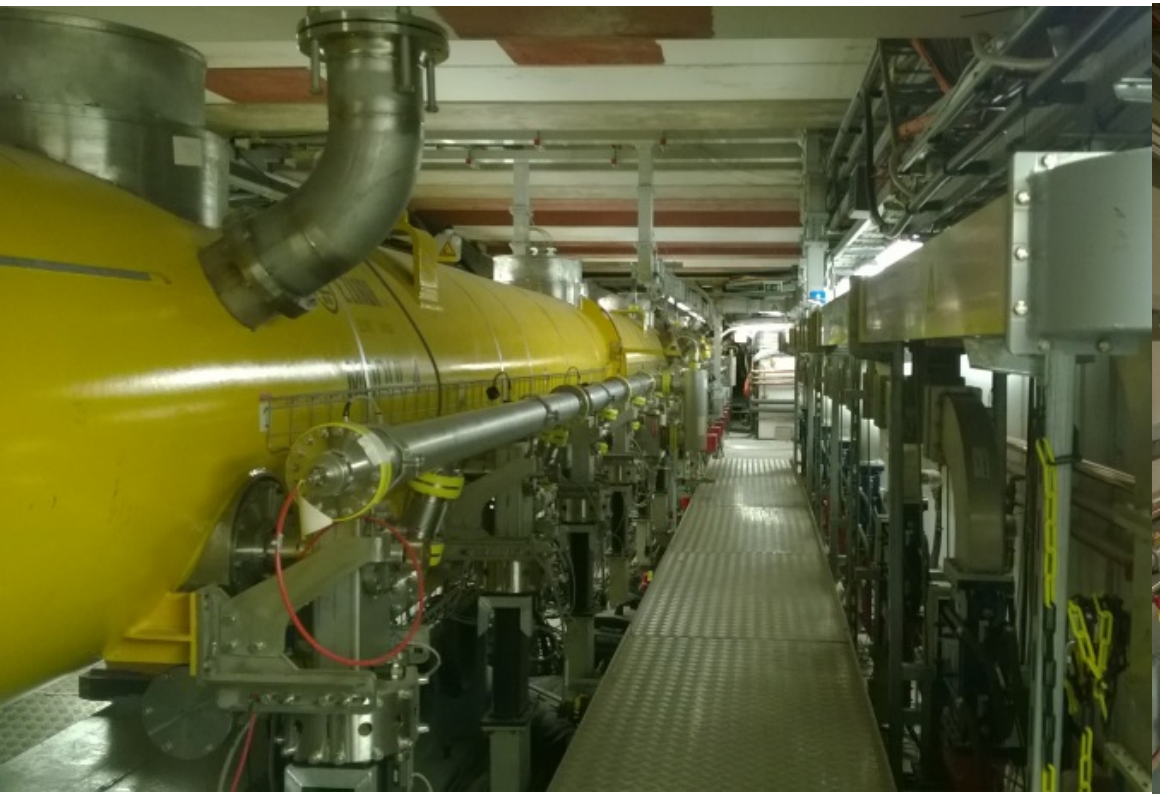
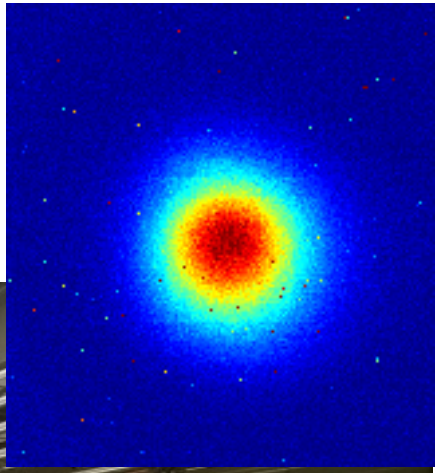
Energy calibration





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Hamburg, July 03, 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Energy measurements at FLASH1 and FLASH2

FLASH1:

- Energy Server
- LLRF Vector sum

FLASH2:

- Dipole current
- LLRF Vector sum

Why is knowledge of the energy and energy (profile) important

- Energy scalability
- Correct optics

Procedure followed.

1. Set energy to approximately 450, 600, 750, 900 and 1050 MeV
2. At each energy
   - Measure FLASH1 LLRF Energy gain.
   - Measure energy according to energy server.
   - Measure FLASH1 wavelength.
   - Measure FLASH2 LLRF Energy gain.
   - Measure wavelength for a given undulator gap.
   - Adjust energy fudge FLASH2 until SP and RBV wavelength are identical.
   - Check wavelength at FLASH2 for two additional undulator gaps.

Important additional information.

- The energy gain (on-crest phases) assumes that the energy in BC2 and BC3 does not change
- If the amplitudes or phases of the modules drift, the on-crest information is no longer correct (has been checked at the beginning and at the end)
- Since steps are used, the energy in FLASH1 and FLASH2 is not the same.
- If we are going off-axis through the undulators, the wavelength is longer than predicted by the energy and undulator K.
- Energy server value in FLASH1 depends on H8TCOL value.

Results for FLASH2

The energy fudge at FLASH2 does not depend on the undulator gap → assumed is that difference is an inaccuracy in the energy measurement.

Energy VS	Energy VS corr.	Energy fudge (%)	Corrected Energy
1032.6	1027.6	1.25	1045.51
886.4	882.3	0.55	891.28
747.7	745.8	0.46	751.14
603.2	604.4	0	603.20
447.2	445.3	-0.09	446.80

- Energy VS is what is given by DOOCS.
- Energy VS corr. Is corrected for different energy in BC2 and BC3.
- Corrected Energy is the energy needed to explain the wavelength (= include fudge).

Results for FLASH1

The energy fudge at FLASH2 does not depend on the undulator gap → assumed is that it is an inaccuracy in the energy measurement.

Energy VS	Energy VS corr.	Energy server dogleg	Wavelength fudge (%) / Energy fudge (%)	Corrected Energy
1040.7	1037.3	1030.6	-3.5 / 0.85	1055.38
896.8	892.3	887.21	-2.8 / 0.39	901.38
751.8	749	742	-3.3 / 0.45	754.36
602.5	603.7	596	-1.5 / -0.29	602.50
448.3	446.8	443	-1.26 / -0.61	448.30

- Energy VS is what is given by DOOCS.
- Energy VS corr. Is corrected for different energy in BC2 and BC3.
- Energy server is the energy calculated from the orbit in the dogleg.
- Wavelength or energy fudge is the relative difference in wavelength between measured and calculated using the energy server or the difference between energy calculated from the measured wavelength and the LLRF VS.
- **Corrected Energy is the energy calculated from the result in FLASH2 (value for FLASH2 times ration VS FLASH1 and FLASH2)**.

Fitting of FLASH1

Assume a 2.5% difference in ACC67, 1.5% in ACC45 and -0.8% in ACC1 between SP and actual energy gain

FL1 Energy	FL1-fit	E-diff (%)	WL FL1	FL1 fitted	Wl-diff (%)
1055.3	1050.5	0.463136	5.685	5.708	0.40
901.3	903	-0.1799	7.726	7.726	0
754.3	755.1	-0.09774	10.98	11.048	0.61
602.5	603.9	-0.23186	17.35	17.273	-0.44
448.3	447.1	0.268609	31.54	31.51	-0.09

FL1 Energy is the energy deduced from a scaled value in FLASH2
FL1-fit is the energy fitted from the DOOCS SP and the assumed error made in the calibration

Energy in FLASH2

FL2 Energy	FL2-fit	E-diff (%)
1045.5	1042.5	0.28
891.2	893.6	-0.26
751.1	751.2	-0.01
603.2	604.6	-0.23
446.7	446.6	0.04

FL2 Energy is the energy measured.
FL2-fit is the energy fitted from the DOOCS SP and the assumed error made in the calibration.
E-diff is the energy fudge needed to predict the correct wavelength in FLASH2 (should have been zero).

On-crest phases.

	Gun	ACC1	ACC39	ACC23	ACC45	ACC67
2018-04-02	-1.3	2.4	4	-1.5	0.2	?
2018-04-04	-2.7	0.5	1	-4.4	-1.8	?

- The largest deviations in energy were observed due to differences in ACC45 and ACC67
- At the same time, the ACC23 and ACC45 phases have changed significantly over 2 days.
- The phase difference does not explain the energy difference (it is clear from the analysis that the energy is higher than given in DOOCS), but makes the error bars in the calculations significant.

Conclusion

- Once a fudge factor between measured energy and energy calculated for a given wavelength at FLASH2 has been determined, this factor is valid independent of undulator gap. Taking this energy also for FLASH1 with the undulator K-parameter which is used for the FLASH1 undulator, the error made in the wavelength is below 0.5%.
- The calibration error especially in ACC45 and ACC67 is large enough to cause an energy error exceeding 1%.
- Since LLRF can and will drift over a period of hours or days, there is still the need for an energy FB as the one in the FLASH1 dogleg to stabilize the beam energy, also for FLASH2.
- The real vector sum should be calculated, including the effect of deviating energies in BC2 and BC3.
- One should consider using the BAMs in BC2 and BC3 to determine the absolute energy gain of ACC23, which cannot be easily determined otherwise. The influence of orbit differences should be checked. As soon as a UBC2 BAM is available, the same should be done for ACC1+ACC39.

Thank you