

Introduction

Free-electron lasers operated in the soft- and hard X-ray spectral range like LCLS, SACLA, and FLASH are based on the SASE-principle. The spectrum of the amplified radiation is subject to statistical fluctuations due to the stochastic nature of the start-up process from shot noise. FEL seeding has proven to stabilize the spectral and temporal distribution of the FEL pulse and with that providing good temporal coherence. Using external laser pulses as seed for the FEL process has the advantage that these pulses will be intrinsically synchronized with the FEL pulses, thus giving the possibility for pump-probe experiments with highest temporal resolution only limited by the individual pulse lengths. Here, we present our plans to further develop the seeding technology towards shorter wavelength and shorter FEL pulses with peak-power in the GW level and full longitudinal coherence at FLASH. The latest results in this field will be taken into account for the final design for seeding at FLASH2.

The vision

Provide fully coherent FEL radiation pulse to users at wavelengths down to water window, with perspective down to 1 nm, at timing control in the few fs regime.

Status of seeding technology

	Minimum wavelength	Pulse length & Pulse energy	Limits
High-gain harmonic generation (HGHG) [1]	20 nm FERMI	~70 fs 30 μJ	FEL power (~1 GW)
Staged HGHG [1]	4 nm (staged) FERMI	< 25 fs ~1 μJ	FEL power (<1 GW) Intensity stability
Echo-enabled harmonic generation (EEHG) [1]	171 nm NLCTA	? ?	Minimum wavelength (limited beam energy)
Direct seeding (with HHG) [2]	38 nm FLASH	< 40 fs 10 μJ	Low seed success rate Limited contrast
Harmonic cascading (HC) [2]	19 nm FLASH	< 40 fs	Low seed success rate Limited contrast
Self-Seeding [3]	0.12 nm LCLS	5 fs 60 μJ	Intensity stability No synchronization

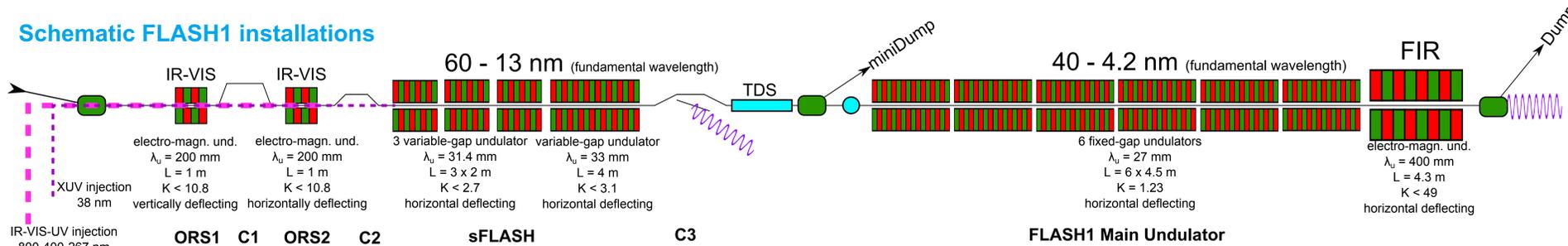
Demands by FEL users

On the bases of a questionnaire on seeding for the recent workshop "Opportunities for FLASH2 beamlines" we identified these points as the most important demands for seeding:

- > Stable pulse parameters
- > Stable (smooth) spectrum / time structure
- > Wavelength range < 10nm - 30 nm
- > Pulse energy > 20 μJ
- > Pulse duration mainly 30-50 fs (FWHM)
- > "good" timing stability
- > 10 Hz is acceptable (as first step ...)
- > Wavelength tunable
- > Sufficient diagnostics

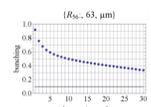
Seeding development at FLASH1 - Towards high peak-power fully coherent FEL radiation

Schematic FLASH1 installations



CHG (coherent harmonic generation)

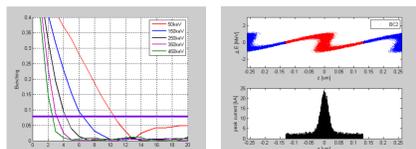
Planned for March/April 2014
 $\lambda_{seed} = 267$ nm ; $T_{seed} < 50$ fs
 Modulator: ORS1
 Bunching chicane: C1, C2 or C3
 Radiator: sFLASH4, FLASH
 no electron compression -> energy spread < 10 keV
 expected signal-to-noise ratio: $\frac{N_{coherent}^2}{N_{incoherent} N_b} > 1000$
 Use CHG signal to determine upper limit for slice energy spread
 Test of laser-electron overlap with 267 nm



Bunching factor for 10 keV slice energy spread with 500 keV induced energy modulation

HGHG (high gain harmonic generation)

Planned for May 2014
 $\lambda_{seed} = 267$ nm
 Modulator: ORS1
 Bunching chicane: C1 or C2
 Radiator: sFLASH (4th harm. and higher)
 Electron peak current: 0.5 - 1.5 kA



Bunching factor for different slice energy spreads [4]

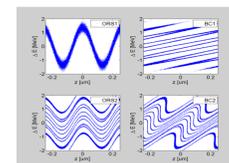
Double-pulse seeding

Planned for June/July 2014
 Single-laser approach [5]:

 $\lambda_{seed 1} = 267$ nm; 6 GW seed power; vert. polarized
 Modulator 1: ORS1
 $\lambda_{seed 2} = 266$ nm; 1 GW seed power; hori. polarized
 Modulator 2: ORS2
 Use TDS to detect energy modulation for both laser pulses

EEHG (Echo-enabled harmonic generation)

Planned for June/July 2014
 $\lambda_{seed 1} = 266$ nm; 6 GW seed power; vert. polarized
 Modulator 1: ORS1
 Folding chicane: C1; R56 < 700 μm
 $\lambda_{seed 2} = 266$ nm; 1 GW seed power; hori. polarized
 Modulator 2: ORS2
 Bunching chicane: C2; R56 < 130 μm
 Radiator: sFLASH



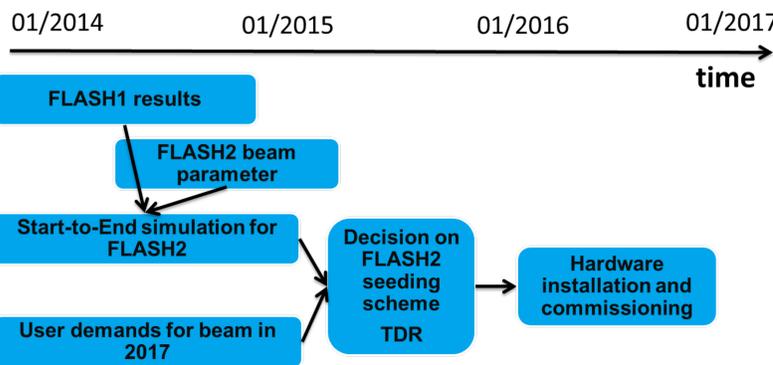
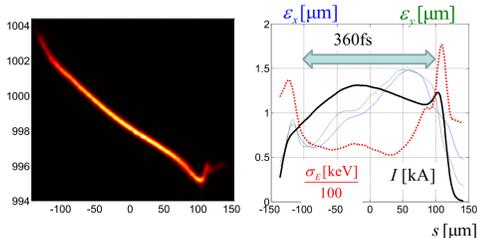
Seeding of FLASH2

Design goal:
 Provide high peak-power (> 1GW) seeded FEL pulses below 30 nm with sub 50 fs pulse duration

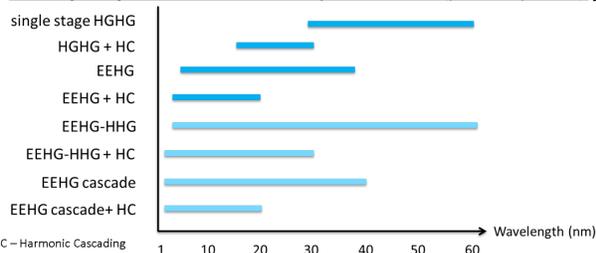
Constraints for seeded operation of FLASH2

- > permit SASE operation in FLASH2 from 4 - 80 nm
- > Seeded operation of FLASH2 has to be compatible with FLASH1 SASE operation
- > efficient beam transport of seeded FEL radiation to FLASH2 user hall

Electron bunch at the entrance of the FLASH2 section from start-to-end simulations



Wavelength ranges for different schemes compatible with SASE (preliminary studies); [6]



Detailed simulation for promising seeding schemes are carried out and will be benchmarked by experimental studies at FLASH1. A technical design report for seeding FLASH2 is planned for early 2015.

Summary

- > Experiments to explore the generation of sub 50 fs, multi GW FEL pulses planned for 2014
- > Demonstration of EEHG in the XUV wavelength range
- > User demands for the next generation seeded FEL facility
- > Strategy for seeding FLASH2
- > Promising seeding schemes towards shorter wavelengths

References

- [1] In Proceedings FEL conference 2013
- [2] S. Ackermann et al., Phys. Rev. Lett. (2013)
- [3] J. Amann et al., Nature Photonics (2012)
- [4] K. Hacker et al., TESLA-FEL Report 2011-05
- [5] K. Hacker et al., TESLA-FEL Report 2011-06
- [6] K. Hacker et al., TESLA-FEL Report 2013-01

