sFLASH
PRESENT STATUS AND COMMISSIONING RESULTS

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on behalf of the sFLASH group

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Outline

1. Motivation and introduction to sFLASH-layout
2. Commissioning results
   - linac set up
   - transverse, longitudinal and frequency overlap
   - SASE performance
   - HHG-source performance
3. Summary and outlook
Motivation

goals:
⇒ high shot-to-shot stability and high peak power (GW level)
⇒ generation of fully coherent pulses
⇒ wavelength range < 40 nm
⇒ reduction of saturation length
⇒ Temporal stability for pump probe experiments on fs scale

a comparison with the output of an FEL seeded using High Harmonic Generation (HHG)
Motivation

Simulated radiation power as a function of the local distance in the XUV-pulse. The energy in the seeding harmonic is 1 nJ.

- The power contrast $P_{\text{seeded}}/P_{\text{SASE}} \sim 10^3$.
- The energy contrast $E_{\text{seeded}}/E_{\text{SASE}} \sim 10^2$
General requirements

• **spatial overlap** between electron bunch and HHG pulse
  \[\Delta x, \Delta y < 100 \, \mu m, \Delta x', \Delta y' < 100 \, \mu \text{rad}\]

• **stable HHG parameters** (pulse energy, chirp, frequency …)

• sub-100 fs **temporal overlap** between electron bunch and laser pulse

• **wavelength overlap** \[\Delta \lambda / \lambda \leq 2e^{-3} @ 38 \, \text{nm}\]

Required electron bunch parameters

• Normalized transverse emittance < 3 \, \mu m,

• Peak current > 1kA

• Energy chirp < 0.1\,\text{MeV/\mu m}, slice energy spread \[\sigma_E / E < 2e^{-3}\]

• Nominal conditions: \(I \approx 1.5 \, \text{kA}, E \approx 700 \, \text{MeV}\)
FLASH layout

- Normal conducting 1.3 GHz RF gun
- Ce$_2$Te cathode
- Nd:YLF based ps photocathode laser

3rd harmonic cavity 3.9 GHz

TESLA type superconducting accelerating modules

Fixed gap undulator
- length ~ 27 m

FEL Experimental Hall

3rd harmonic cavity 3.9 GHz

RF gun

Accelerating Structures

Bunch Compressor
- 5 MeV
- 150 MeV
- 450 MeV
- 1250 MeV

Diagnostics and matching

315 m

Bunch Compressor

Bypass

Undulators

Undulator

THz

FEL Experiments

LOLA

RF Gun THz

FLASH layout

FEL Experiments

Diagnostics and matching

sFLASH undulators
sFLASH building blocks

hutch for first experiments with sFLASH pulses

Ti:Sa laser system and HHG source
sFLASH building blocks

- Hutch for first experiments with sFLASH pulses
- Ti:Sa laser system and HHG source
sFLASH building blocks

- FEL extraction
- Undulator section
- ORS* section
- Seed injection
- HHG source

* Optical Replica Synthesizer
HHG source schematic

about 2nJ at 38nm

courtesy M. Mittenzwey

adjustable iris for differential pumping

800 nm into pit

xuv radiation to FLASH

to / from trunks

differential pumping stages

focusing mirror

high harmonic generation
HHG injection beamline

- Injection and focusing of the XUV-seed, transmission $\leq 20$
- Control of seed position along undulators

One fixed $f$ focusing mirror

courtesy J. Boedewadt

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HHG injection beamline

courtesy J. Boedewadt
Layout of the sFLASH photon beamline

YAG screens and apertures

To experiment

Mirror chambers

Spectrometer

Intensity monitor
Layout of the sFLASH photon beamline

- Spectrometer
- YAG screens and apertures
- Mirror chambers
- Intensity monitor
- To experiment
HHG seed characterization

- HHG energy @ 38nm at the source $\approx 2$ nJ
- Full HHG energy at the undulator $\approx 0.4$ nJ (the best case with 20% transmission)
- HHG energy coupled to electron beam $\approx 0.016$ nJ (due to $\sigma_{\text{HHG}} >> \sigma_{\text{e-beam}}$)
- Effective seed power $\approx 800$ W. Shot noise power $\sim 100$ W
- Photon diagnostics integrates over radiation pulse $\rightarrow$ Energy contrast $\sim 1 \Rightarrow$ difficult to demonstrate seeding
HHG seed characterization

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• Four planar **variable-gap** undulators of **10m total length** with period of **31.4mm and 33mm**
• Wire scanners, OTR stations, YAG screens, BPMs in undulator intersections
• Two air coils per undulator to compensate the residual field integrals
• Magnetic measurements and tuning performed at a measurement bench
Undulator commissioning

Beam position as a function of the gap of the first sFLASH-undulator

✓ ⇒ Tolerable impact on the orbit for any undulator gap
Linac set up

$E \approx 700 \text{ MeV}$

$Q \approx 1 \text{ nC}$
Linac set up

\[ E \approx 700 \text{ MeV} \]

\[ Q \approx 1 \text{ nC} \]

\[ \langle \beta \rangle \leq 6 \text{ m} \]

\[ \beta_x \]

\[ \beta_y \]

\[ \text{design optics} \]

\[ \text{e}^- \text{ beam} \]

\[ \text{Z (m)} \]

195 190 185 180 175 170 165 160 155 150 145

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Linac set up

Electron bunch size in sFLASH-undulator area

$90 \mu m < \sigma_{xy} < 180 \mu m$
Concept for finding the transverse overlap

XUV beam profiles

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Concept for finding the transverse overlap

Superimposed beam profiles measured on Ce:YAG screen

upstream Undulator 1

downstream Undulator 1

\[ \Delta X, \Delta Y < 50 \ \mu m \]

\[ \theta < 50 \ \mu \text{rad}, \quad \Rightarrow \]

\[ \Delta \lambda / \lambda = \frac{\gamma^2 \theta^2}{1 + k^2} \]
Concept for finding the temporal overlap

1) Streak camera measurement using spontaneous undulator radiation and HHG-drive laser → 0.5 ps resolution

2) Modulator-radiator based system using coherent light from the radiator → <100 fs

~ 0.5 ps (coarse) overlap

sub-100 fs (fine) overlap
Coarse temporal overlap

Temporal overlap (~0.5 ps) between the HHG drive laser pulse and spontaneous undulator radiation measured with the streak camera.
Demonstration of sub-100 fs temporal overlap

(left)-Measurement of the intensity of the emitted coherent radiation as a function of the relative delay (25 fs step) of the IR-pulse. The temporal overlap between the IR-light and the electron bunch enhances the radiation intensity.

(right)-Longitudinal charge distribution measured with transverse deflecting cavity. To be compared with the measurement in the left.
Demonstrating the frequency overlap

(Left) Single-shot spectra of the SASE-radiation.

(Right) Single-shot spectra of the HHG seed.

The red curve is the average over all single shots.
Mandatory! Proofs, that the FEL-amplifier works at the right wavelength with sufficient gain in linear regime ($1e5-1e6$)

$$p_E = \left( \frac{M^M}{\Gamma(M)} \right) \left( \frac{E}{<E>} \right)^{M-1} e^{-\frac{ME}{<E>}} / <E>$$

$M=6.8\pm0.6$

$\tau_c \approx 7 \text{ fs}$
Summary and outlook

- sFLASH fully commissioned (300 hours FLASH beamtime)
- \{X,Y,X',Y',t,\lambda\} overlap demonstrated
  - \Delta X, \Delta Y < 50 \, \mu m, \Delta X', \Delta Y' < 50 \, \mu rad
  - \Delta t < 100 \, fs
  - \Delta \lambda/\lambda < 0.001
- sFLASH-SASE achieved on regular basis
- HHG-source generates up to 2nJ@38 nm

**sFLASH upgrade (starting September 2011)**
- 1-stage 800 nm compressor \(\rightarrow\) \(\sim 3\) times more energy in IR
- Adaptive optics in injection beamline \(\rightarrow\) improved coupling
- Additional XUV-diagnostics \(\rightarrow\) online HHG characterization after injection
- Resume operation beginning 2012