SHORT SASE-FEL PULSES AT FLASH.

Universität Hamburg
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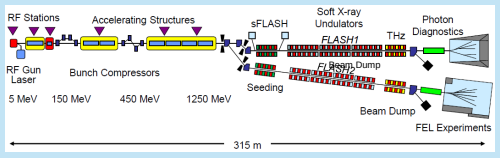
DESY

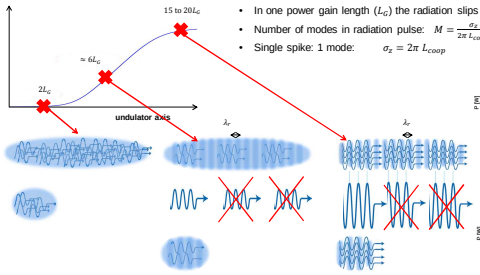
Introduction

FLASH is a high-gain free-electron laser (FEL) in the soft x-ray range. This paper discusses the production of very short FEL pulses in the SASE-mode without an external seeding signal at FLASH in the optimal case the single-spike operation. A new photo-injector laser has been commissioned, which allows the generation of shorter bunches with low bunch charge directly at the photo-cathode. This shorter injector laser reduces the required bunch compression for short pulses and thus allows a stable SASE performance with shorter pulses. First SASE performance using the new injector laser has been demonstrated and electron bunch and FEL radiation properties have been measured. Beam dynamics as well as the optimization of bunch diagnostics for low charge and short bunches are discussed.

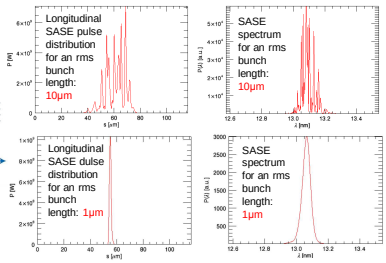
FLASH



Single Spike Operation



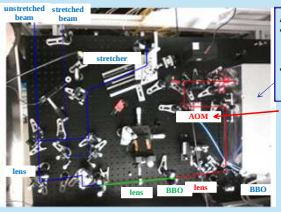
- In one power gain length (L_G) the radiation slips forward one cooperation length : $L_{coop} = \frac{\lambda_r}{\lambda_u} L_G$
- Number of modes in radiation pulse: $M = \frac{\sigma_z}{2\pi L_{coop}}$
- Single spike: 1 mode: $\sigma_z = 2\pi L_{coop}$



New short pulse injector laser

	Typ. FLASH parameters	Single spike operation at FLASH	Single spike operation at FLASH
Injector laser pulse duration (FWHM)	15.3 ps	15.3 ps	1-3 ps
Bunch charge	0.08 - 1 nC	20 pC	20 pC
Bunch duration (rms)	30 - 200 fs	3 fs	3 fs
compression	220 - 32.5	2200	140-430
FEL pulse duration (FWHM)	30 - 200 fs	3 fs	3 fs

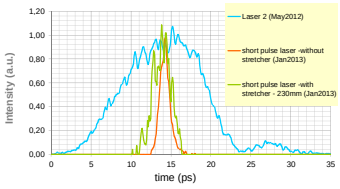
➢ **Shorter photo-injector laser pulse is required**
a large compression factor (~1000) cause RF tolerances of 0.0014° phase tolerance (3fs!) and 0.003% amplitude tolerance



Amplified Laser System:
- Seed laser Origami 10 (OneFive)
  - 1030nm, 260mW, 54MHz, 400fs
- 2 stage amplifier (Amphos)
  - 1030nm, 10W, 1MHz, ~600fs (10µJ)

Acousto-optic modulator (AOM) - pulse picker (pulse trains of 10Hz, with 1MHz pulse repetition)

2 BBOs (forth harmonic)
- 1030nm -> 257.5nm
- (10% efficiency @ 10µJ) -> 1µJ

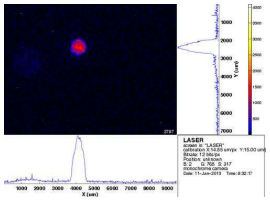


Measured temporal distribution of standard FLASH injector laser compared to short pulse laser.

Measured Laser properties for first SASE

Bunch duration of short pulse laser:
without stretcher: 1.3 ps (FWHM)
with stretcher: 2.4 ps (FWHM)

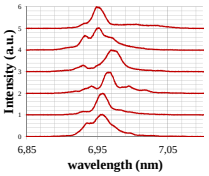
The transverse laser spot was formed with an iris and had a diameter of 1 mm.



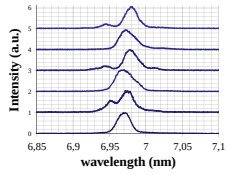
Short Pulse Laser on Virtual cathode with a beam shaping aperture (BSA) of 1 mm (diameter)

Almost single spike

May 2014, bunch charge: 80 pC
Analysis of single FEL pulse spectrum:
- λ = 6.97 nm
- in average: 2.7 spikes within the FWHM

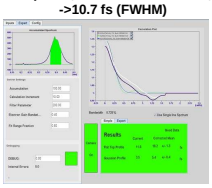


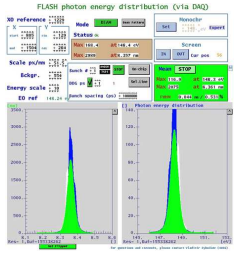
May 2014, bunch charge: 55 pC
Analysis of single FEL pulse spectrum:
- λ = 6.98 nm
- in average: 1.5 spikes within the FWHM



September 2014
- 13 µJ at 45 pC
- e-bunch duration: 40 fs FWHM

1.8 peaks, 1.6 within the FWHM, ->10.7 fs (FWHM)

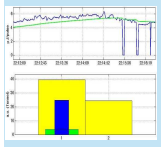


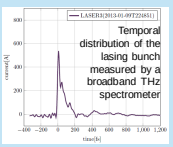


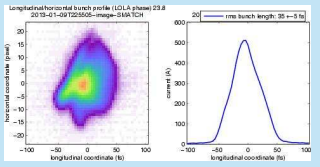
First lasing with new short pulse injector laser

First SASE with short pulse injector laser:
- 9th of January 2013
- 5 uJ at 13,5 nm, bunch charge: 35 pC

parameters	Used parameters
Injector laser pulse duration (FWHM)	2.4 ps
Bunch charge	35 pC
Bunch duration (rms)	35 fs
wavelength	13.5 nm
FEL pulse duration (FWHM)	unknown

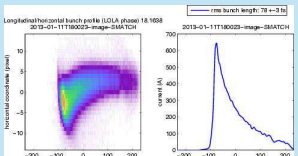




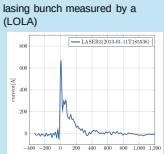


Reproduction of SASE with short pulse injector laser:
11th of January 2013
- 25 µJ at 13 nm, bunch charge: 80 pC

parameters	Used parameters
Injector laser pulse duration (FWHM)	2.4 ps
Bunch charge	80 pC
Bunch duration (rms)	78 fs
wavelength	13.0 nm
FEL pulse duration (FWHM)	~ 50 fs

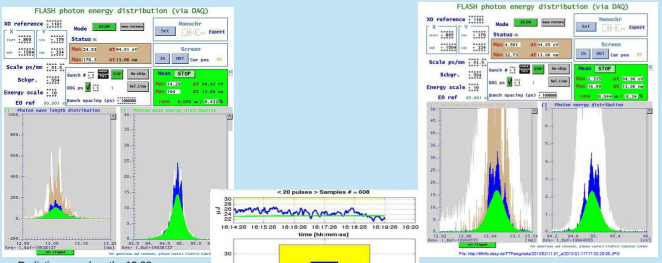


Temporal distribution of the lasing bunch measured by a broadband THz spectrometer



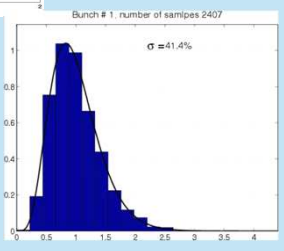
Emittance :
horizontal: 0.9 +/- 0.3 mm mrad
vertical: 0.7 +/- 0.3 mm mrad

in saturation / **exponential growth**



- Radiation wavelength: 13.06 nm
- Fluctuations
  - in the linear regime: 42%

  → Number of modes: M = 5.7
  - in saturation: 13%
- Saturation length: $L_{sat} \approx 22$ m
- Angular divergence in saturation (FWHM) ≈ 40 µrad.
- Spectral bandwidth:
  - in the regime of exponential growth (FWHM): 0.35%
  - in the saturation regime (FWHM): 0.42%
- Radiation pulse length in the linear regime:
- L = (M x λ_{rad} x L_{sat}) / (5 x λ_{Und}) ≈ 40 fs (FWHM)
- **Radiation pulse duration** at full undulator length is estimated as **50 fs**.
- **rms bunch length** of lasing fraction of the electron beam: **40 fs**.
- Assuming Gaussian shape of the electron bunch for the peak current is estimated with I ≈ 700 A. These parameters are consistent with measured properties of the radiation if rms normalized emittance is below 1 mm-mrad.
- Spectral bandwidth of the radiation is pretty **close to** that generated by monochromatic electron beam (**natural SASE bandwidth**). Thus, lasing part of the beam is not disturbed by chirp (due to beam formation procedure or collective effects).



Summary and Outlook

In order to allow a stable single spike operation a new short pulse injector laser was installed, synchronized with FLASH and taken into operation. First SASE operation was demonstrated using this new injector laser. The SASE pulse showed a narrow spectral bandwidth and a high stability. At a bunch charge of 55pC the measured spectral distribution of the SASE pulse with only one to three spikes has been observed. According to beam dynamics studies it is reasonable to gain a single-spike operation at a bunch charge of about 20 pC.

Acknowledgments

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