Commissioning and Diagnostics Development for the New Short-Pulse Injector Laser at FLASH.

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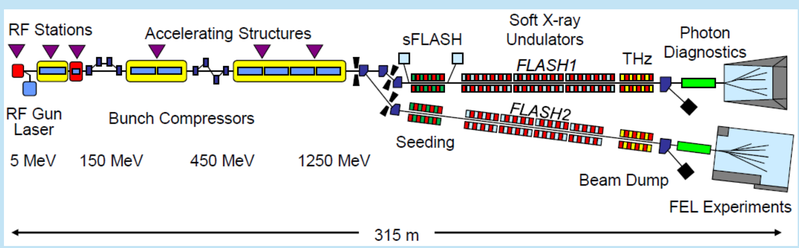
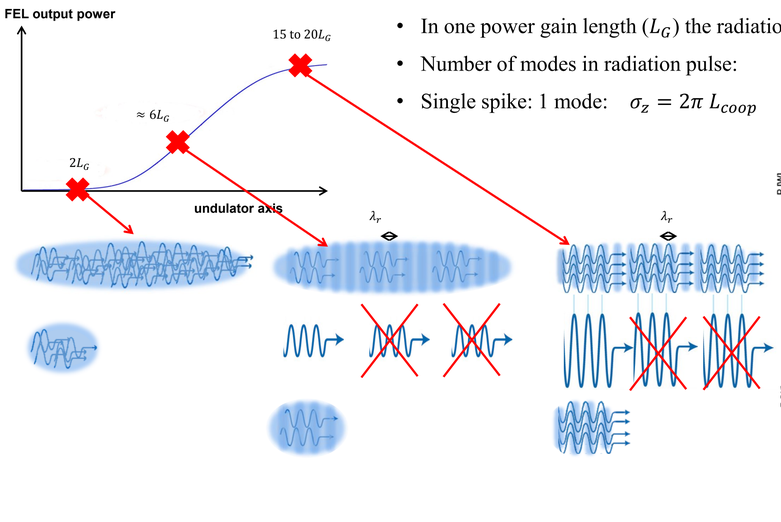
Introduction

In order to extend the parameter range of FLASH towards shorter electron pulses down to a few femto-second self-amplified stimulated emission (SASE) pulses, shorter bunches with very small charges of a few tens of picocoulombs directly at the photo injector are necessary. To achieve so short bunches at FLASH, a new injector laser delivering pulses of 1 ps to 5 ps duration has been installed and commissioned. The influence of the laser parameters on the electron beam was studied theoretically. In this paper we discuss the required laser beam diagnostics and present measurements of critical laser and electron beam parameters.

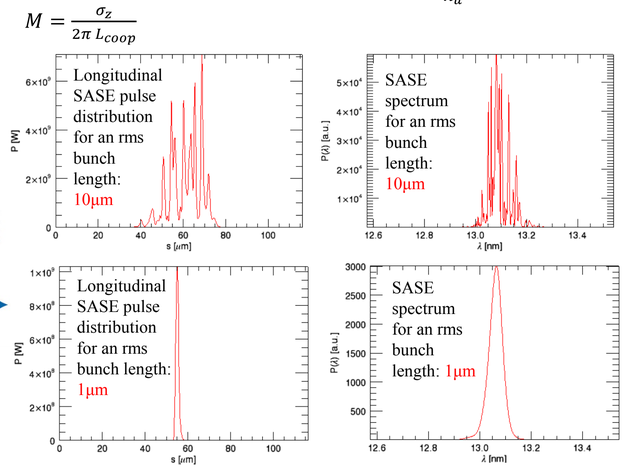
FLASH



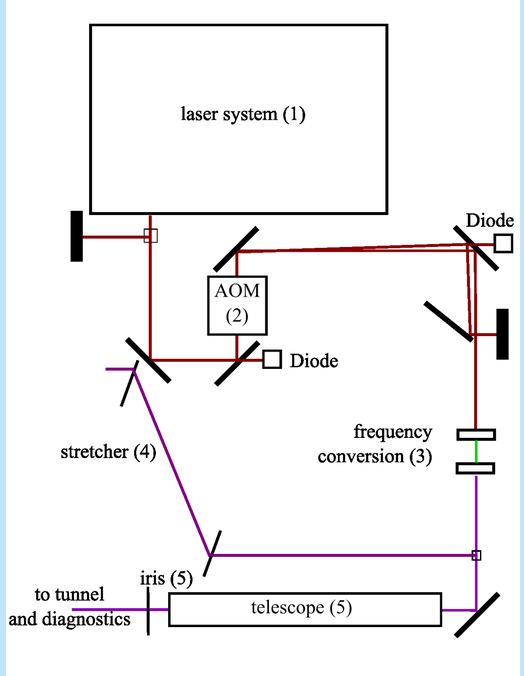
Single Spike Operation



- 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: $\sigma_z = 2\pi L_{coop}$



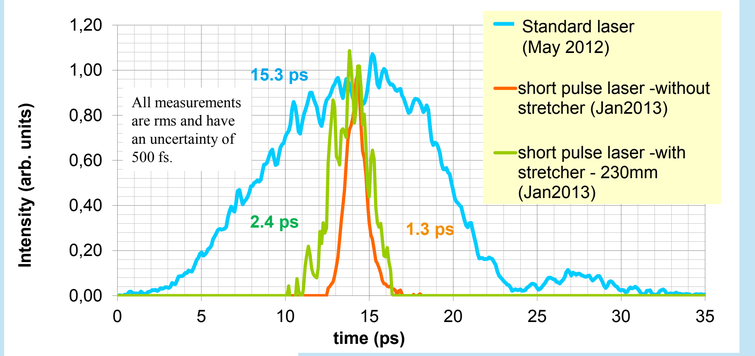
New short pulse injector laser



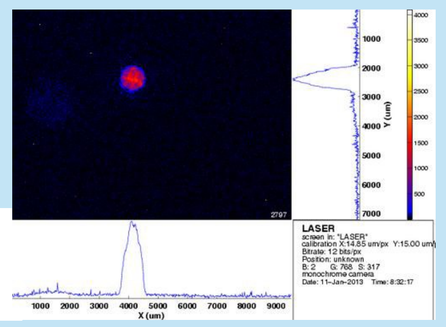
	typ. FLASH parameters	single spike operation at FLASH	single spike operation at FLASH
injector laser pulse duration (FWHM)	15.3 ps	15.3 ps	1-3 ps
bunch charge	0.08 - 1 nC	20 pC	20 pC
bunch duration (rms)	30 - 200 fs	3 fs	3 fs
compression	220 - 32.5	**2200**	**140-430**
FEL pulse duration (FWHM)	30 - 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

(1) laser system
Seedlaser: 260 mW @ 1030 nm, 54 MHz, 400 fs
Amplifier: Two-stage Yb:YAG, 10 W @ 1030 nm, 1 MHz, 800 fs
(2) acousto optic modulator
Allows for arbitrary pulse picking within 10 Hz pulse trains.
(3) frequency conversion
non-critial LBO converts to 515 nm, BBO converts to fourth harmonic at 257.5 nm
(4) stretcher
stretches pulse to a pulse duration of 1 to 5 ps (fwhm), setting can be picked stepless
(5) telescope and iris
variable telescope allows for pulse shaping in combination with an iris of different diameters. (See simulations)



Measured temporal distribution of standard FLASH injector laser compared to short pulse laser. Measurement with streak camera.



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

Parameter Optimisation (Simulations)

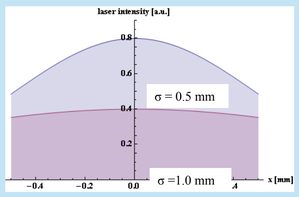
Optimisation of laser profile to reduce space-charge forces and therefore optimise **bunch-duration** and **transverse emittance**.

The scanned laser parameters are laser spot size and aperture size. See (5) in laser system setup section.

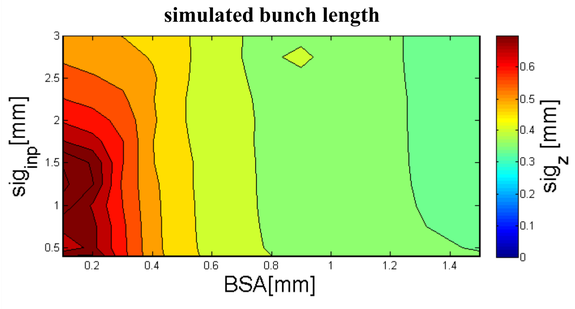
parameter	value
laser pulse duration (FWHM)	2.4 ps
bunch charge	20 pC
macro particles	20 000
gun gradient	50 MV/m
laser spot profile	truncated Gaussian
laser spot size (rms)	0.25 – 3.0 mm
aperture size	0.4 – 3.0 mm

- simulations done using **ASTRA** (simulation of space-charge dominated electron beam dynamics)
- solenoid scan conducted for each parameter set has been done to optimise the magnetic field of the solenoid in terms of minimum emittance

The graph shows a Gaussian distribution cutted at |x| = 0.5 mm (iris, aperture). The curves show distributions with different σ (laser spot size).

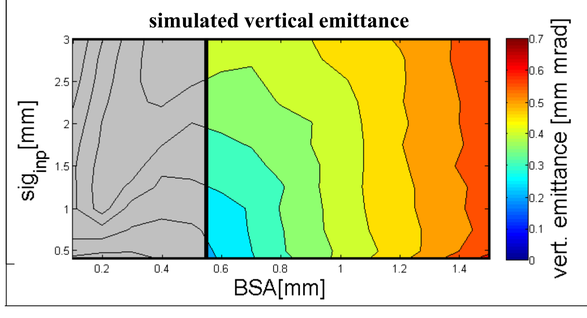


simulated bunch length



Bunch duration of electron bunch before the first accelerating module of FLASH. y-axis shows the laser spot size, x-axis shows aperture size. Bunch duration is colour coded.

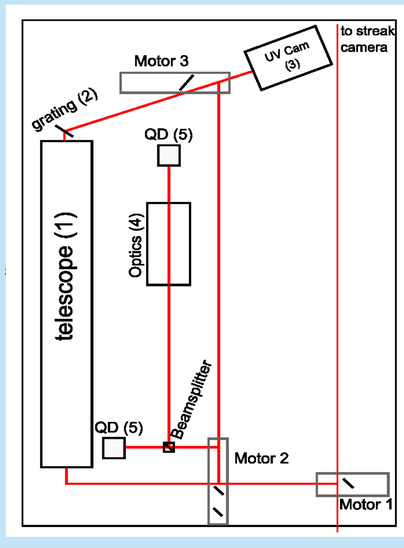
simulated vertical emittance



Vertical emittance of electron bunch before the first accelerating module of FLASH. y-axis shows the laser spot size, x-axis shows aperture size. Emittance is colour coded.

The grey area on the left indicated bunch durations above 0.45 ps, which are not suitable to use for short bunches.

Diagnostics



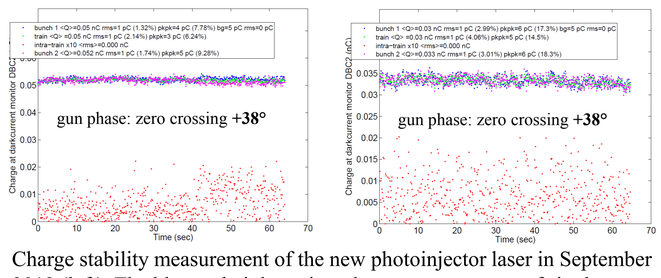
	characteristics	measured laser properties
spectrometer	4000 lines per cm	spectrum
virtual cathode	JAI CM-140 GE-UV	laser position on cathode
quadrant diodes	S4349, amplified	amplitude and position stability
streak camera	Hamamatsu FESCA 200	temporal laser pulse profile

(1) telescope
fixed two lens telescope magnifying by a factor of 5.
(2) grating
transmittive grating with 4000 lines per cm
(3) JAI CM-140 GE-UV
UV camera, pixel width and height of 4.65 µm
(4) optics for imaging laser far field on Quadrant Diode
(5) quadrant diode
Hamamatsu S4349, assembled by DESY Zeuthen, able to measure intra-train laser pulses (1 MHz)

First SASE & measurements

parameters	09.01.13	11.01.13
injector laser pulse duration (FWHM)	2.4 ps	2.4 ps
bunch charge	35 pC	80 pC
bunch duration (rms)	35 fs	78 fs
wavelength	13.5 nm	13.0 nm
FEL pulse duration (FWHM)	unknown	~ 50 fs
FEL pulse energy	5 µJ	25 µJ

Due to the short injector laser only a small compression factor of **25-60** was needed, which significantly improved SASE stability compared to short pulse runs with the standard injector laser.



Charge stability measurement of the new photoinjector laser in September 2012 (left). The blue and violet points show measurements of single bunches in a two-bunch train. The blue dots are averaged values for the train

Charge stability during SASE shift in January (right) has been worse due to strong focussing into frequency conversion crystals.

Outlook

The new photo-injector laser system for short pulse operation at FLASH should be ready for regular operation by the beginning of next year. With the setup of the quadrant diodes the diagnostics will be finished which allows for full characterisation of the laser properties and optimisation of the system.

Acknowledgments

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