Operation of FLASH with Short SASE-FEL Radiation Pulses

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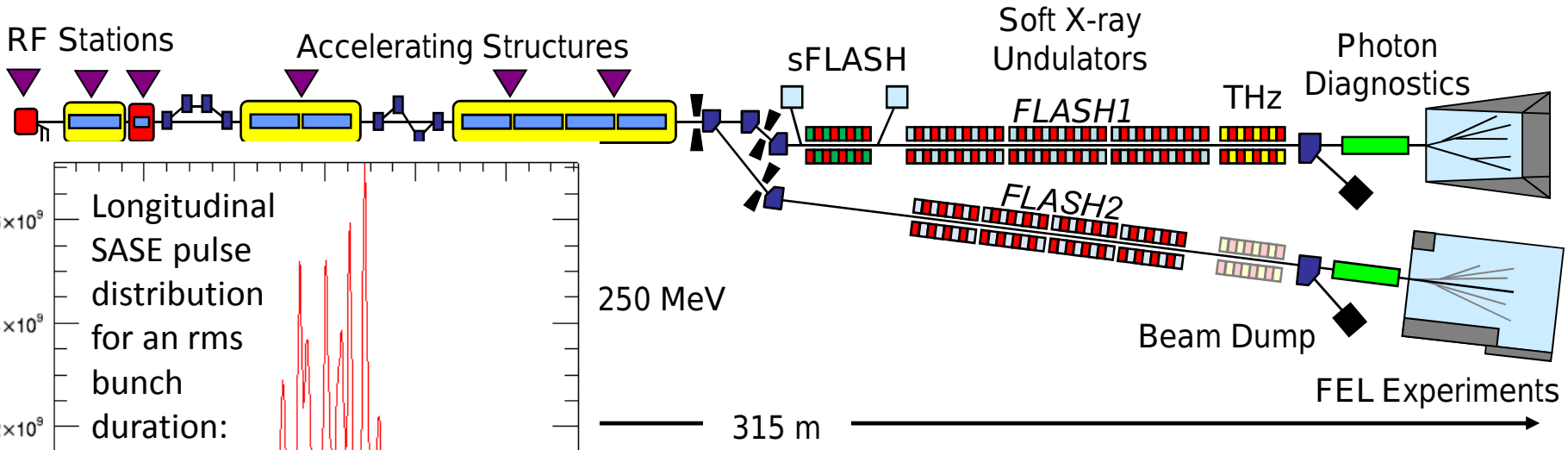
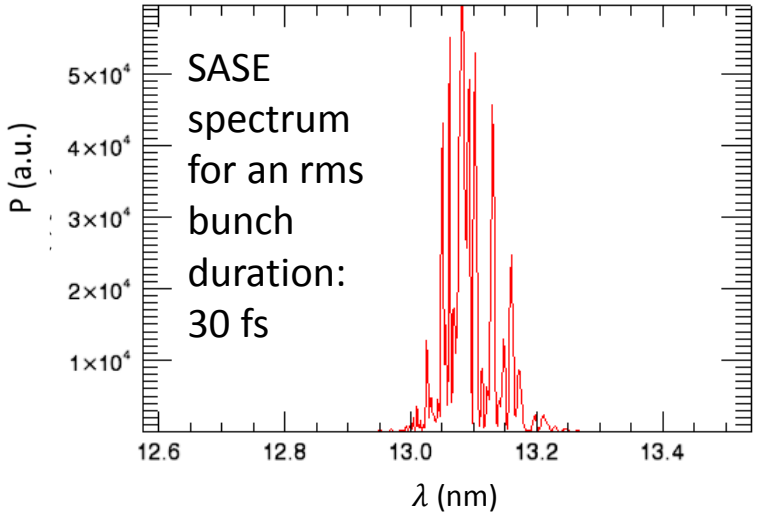
FLASH.
Free-Electron Laser in Hamburg





FEL Radiation Parameters 2014

Wavelength range (fundamental)	4.2 – 45 nm
Average single pulse energy	10 – 500 μJ
Pulse duration (FWHM)	<50 – 200 fs
Peak power (from av.)	1 – 3 GW
Spectral width (FWHM)	~ 0.7 – 2 %
bunch charge	0.08 – 1 nC

K. Honkavaara - WEB05:
"FLASH: …TWO UNDULATOR BEAMLINES …"

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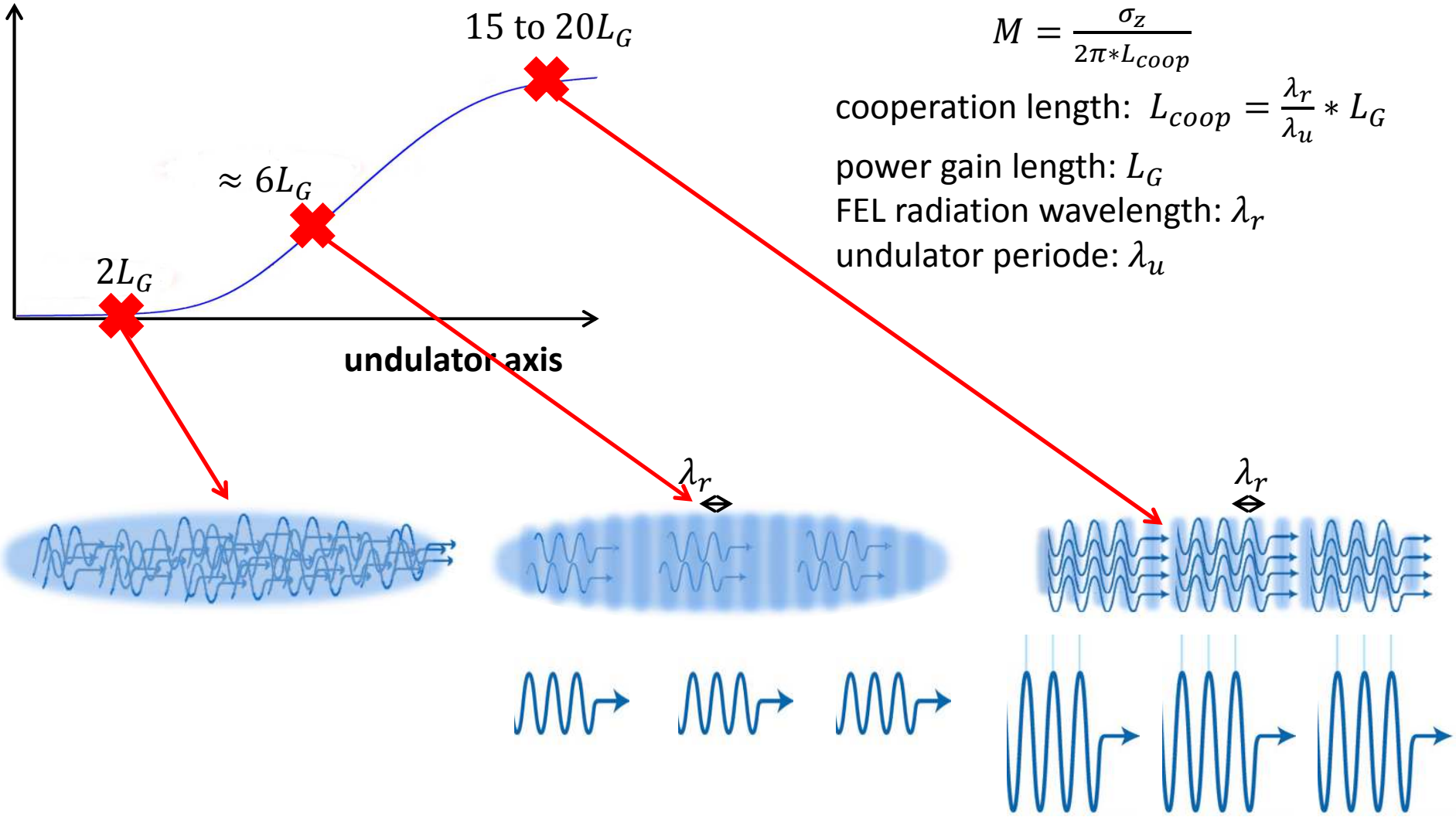

number of modes in radiation pulse:

$$M = \frac{\sigma_z}{2\pi * L_{coop}}$$

cooperation length: $L_{coop} = \frac{\lambda_r}{\lambda_u} * L_G$

power gain length: L_G

FEL radiation wavelength: λ_r

undulator periode: λ_u

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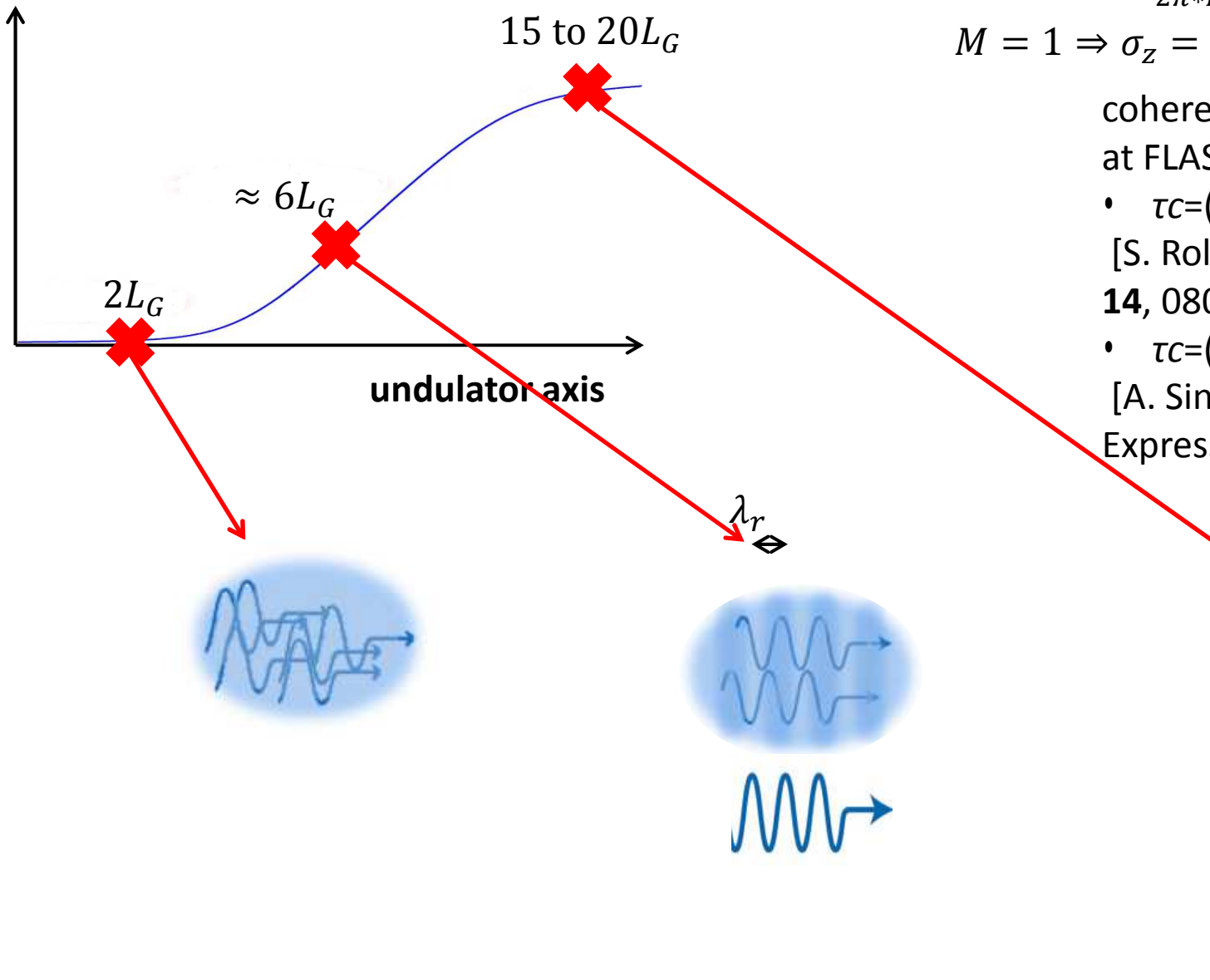
$$M = \frac{\sigma_z}{2\pi * L_{coop}}$$

$$M = 1 \Rightarrow \sigma_z = 2\pi * L_{coop}$$



coherence time measurents at FLASH:

- τc=(2.9±0.5)fs at 8 nm [S. Roling et al., PRSTAB **14**, 080701 (2011)]
- τc=(1.75±0.01)fs at 8 nm [A. Singer et al., Opt. Express **16**, 19909 (2008))]

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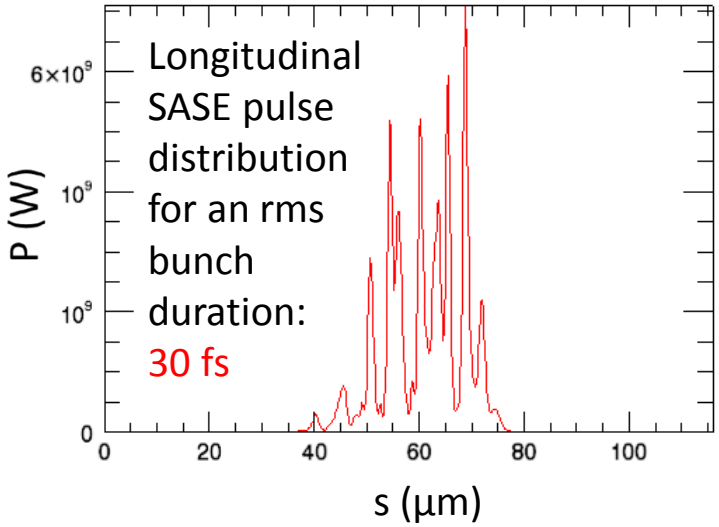
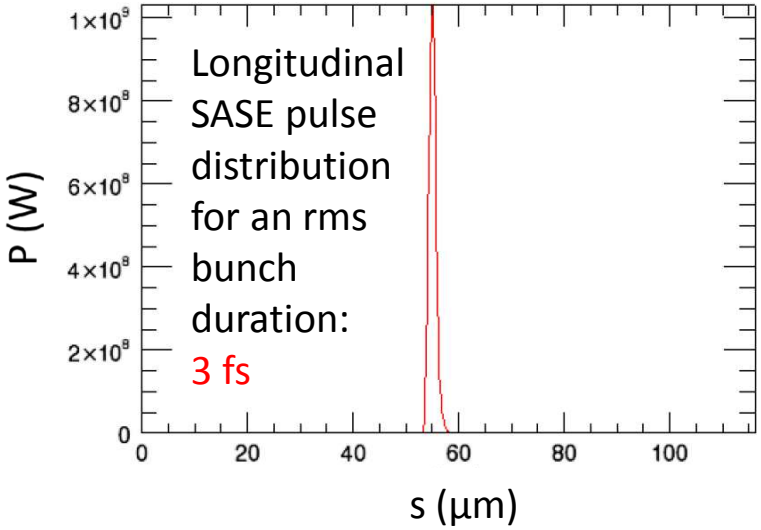
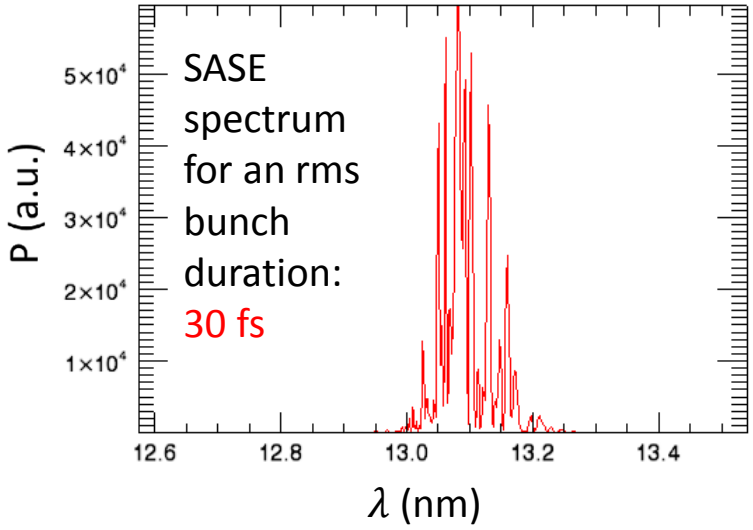
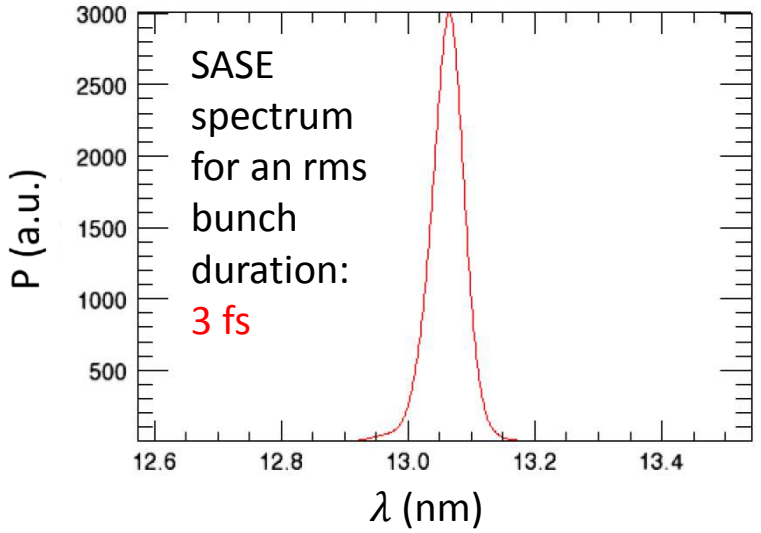








Operation of FLASH with Short SASE-FEL Radiation Pulses

	Typ. FLASH parameters	Single spike operation at FLASH	Single spike operation at FLASH
Injector laser pulse duration (rms)	6.5 ps	6.5 ps	1 ps
Bunch charge	0.08 - 1 nC	20 pC	20 pC
Bunch duration (rms)	30 - 200 fs	3 fs	3 fs
compression	220 - 32	**2200**	**330**
FEL pulse duration (FWHM)	30 - 200 fs	3 fs	3 fs

For FLASH:

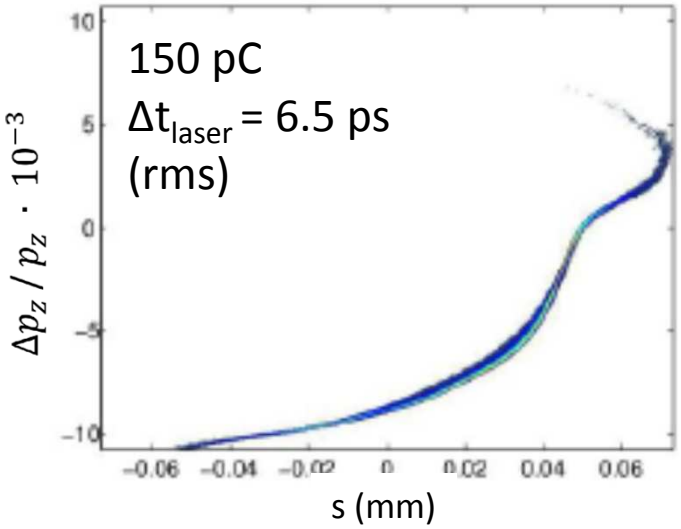
rms bunch length: ~ 3 fs
→ due space charge forces the bunch charge has to be reduced: ~ 20 pC

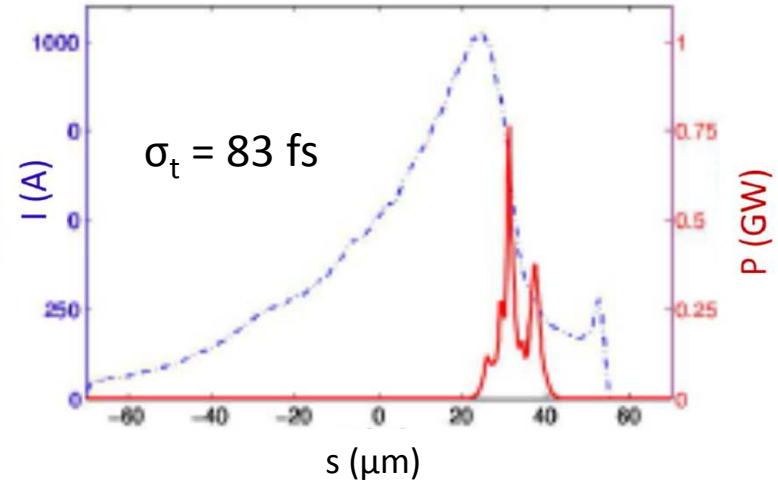
➢ **Shorter photo-injector laser pulse is required**

a large compression factor (~1000) requires RF tolerances of 0.0014° phase tolerance (3fs!) and 0.003% amplitude tolerance

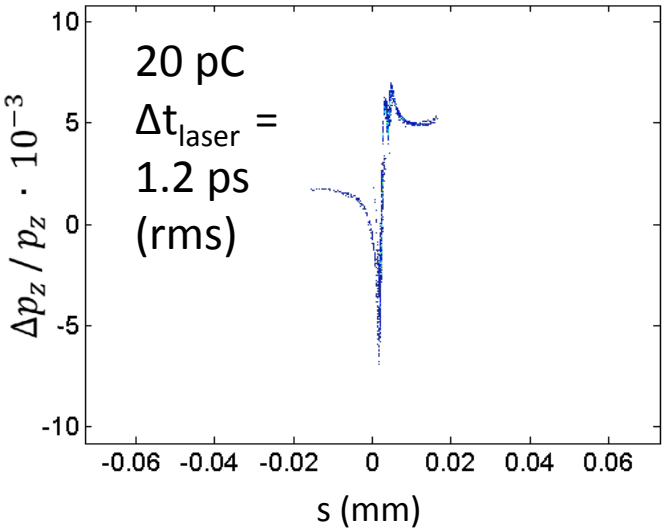
Operation of FLASH with Short SASE-FEL Radiation Pulses

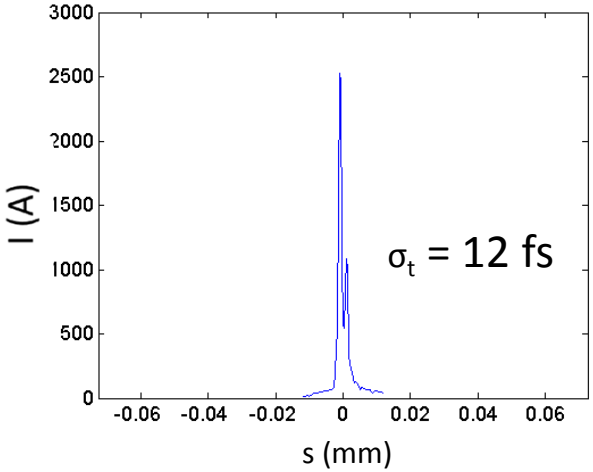
standard short pulse operation
simulated measurement





short pulse operation with short pulse laser
simulation





S. Düsterer - THB01

Operation of FLASH with Short SASE-FEL Radiation Pulses

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FLASH.
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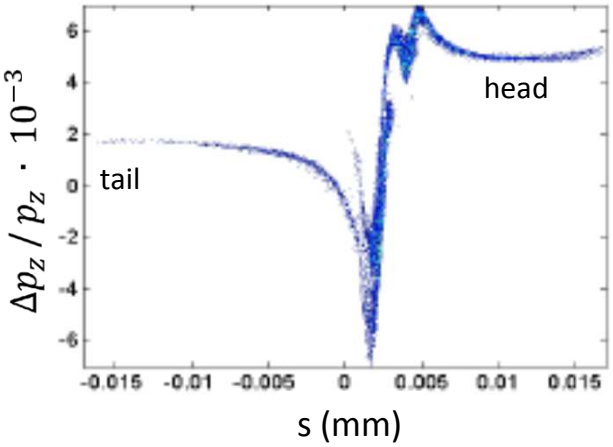
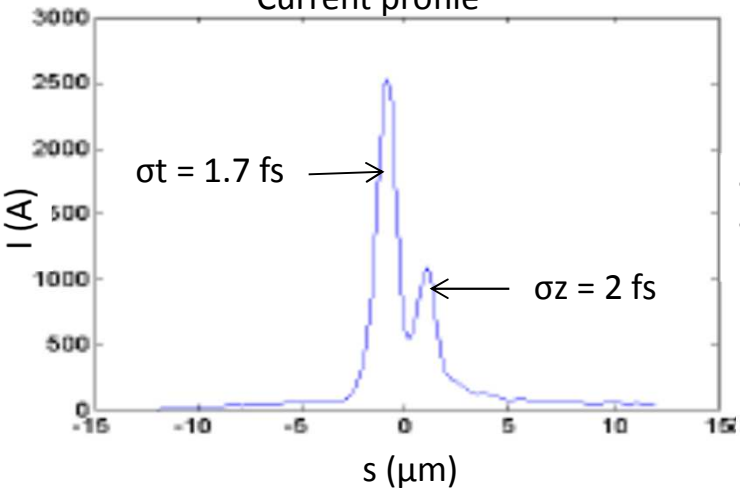
Longitudinal phase space distribution



Simulation

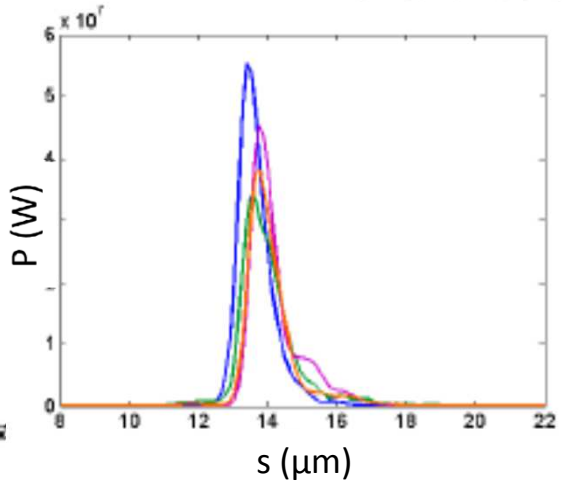
	1st maximum	2nd maximum
peak current (A)	3200	1100
x/y-slice emittance (π mm mrad)	0.8 / 1.1	0.2 / 0.5
slice energy spread (%)	0.16	0.05

Current profile

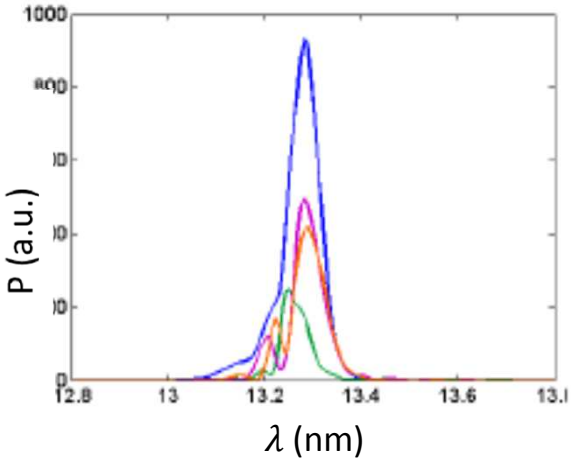


Longitudinal SASE distribution

for four different statistical seeds



SASE spectrum



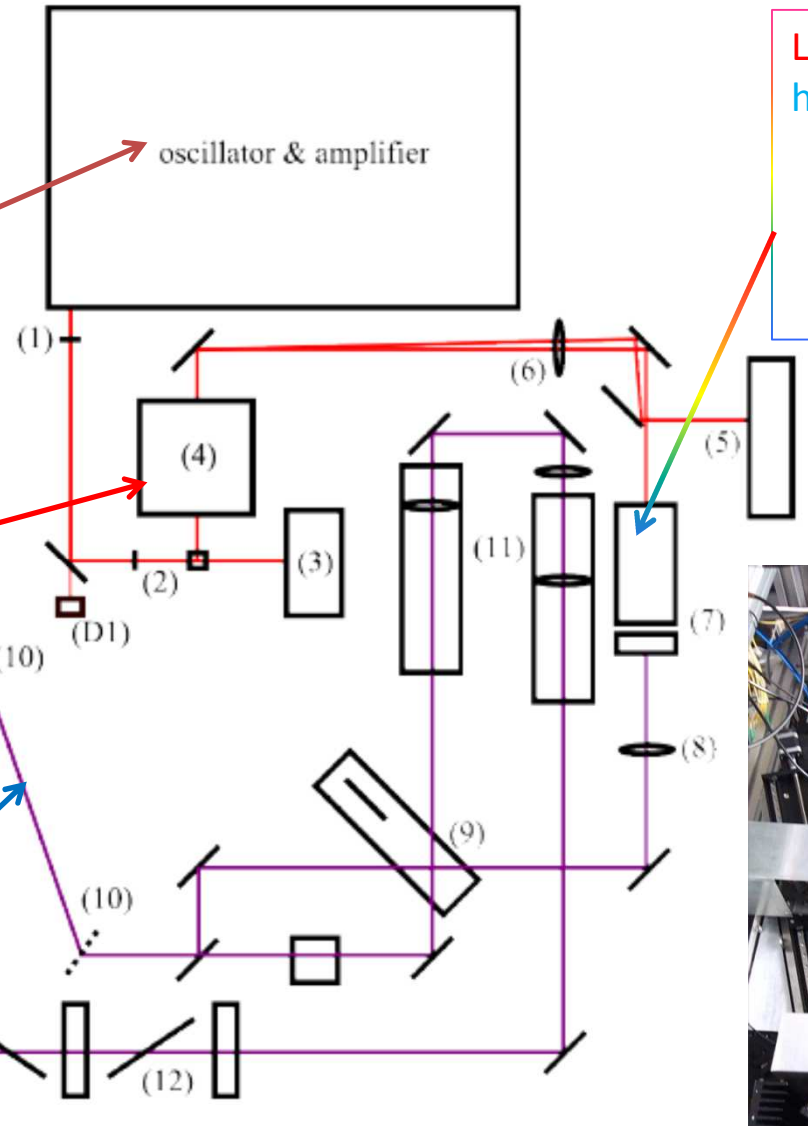
M. Rehders - MOP059

Operation of FLASH with Short SASE-FEL Radiation Pulses

Short pulse injector laser

Amplified Laser System:

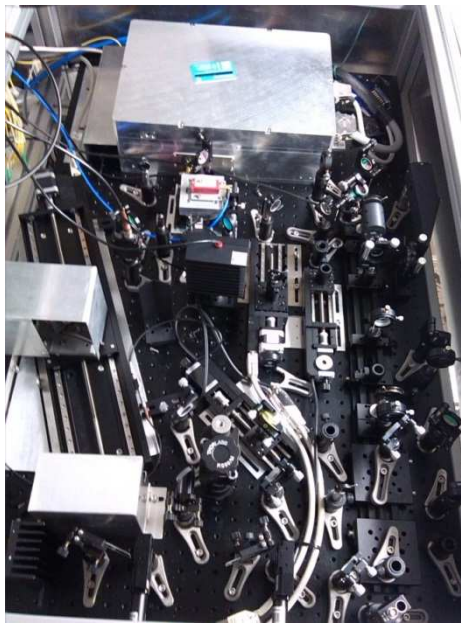
- Seed laser Origami 10 (OneFive)
  - 1030nm, 260mW, 54MHz, 400fs
- 2 stage amplifier (Amphos)
  - 1030nm, 10W, 1MHz, 800fs (10µJ)



LBO + BBO (forth harmonic)

- 1030nm -> 257.5nm
- (10% efficiency @ 10µJ) -> 1µJ

AOM pulse picker (pulse trains of 10Hz, with 1MHz pulse repetition)

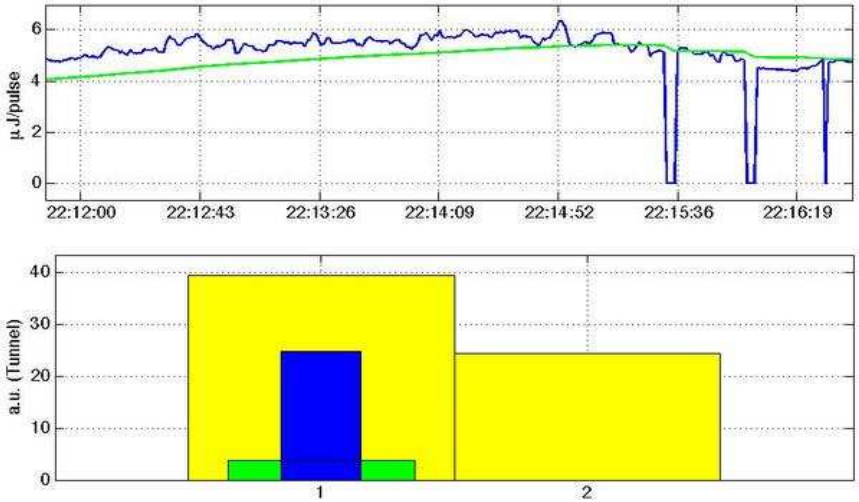


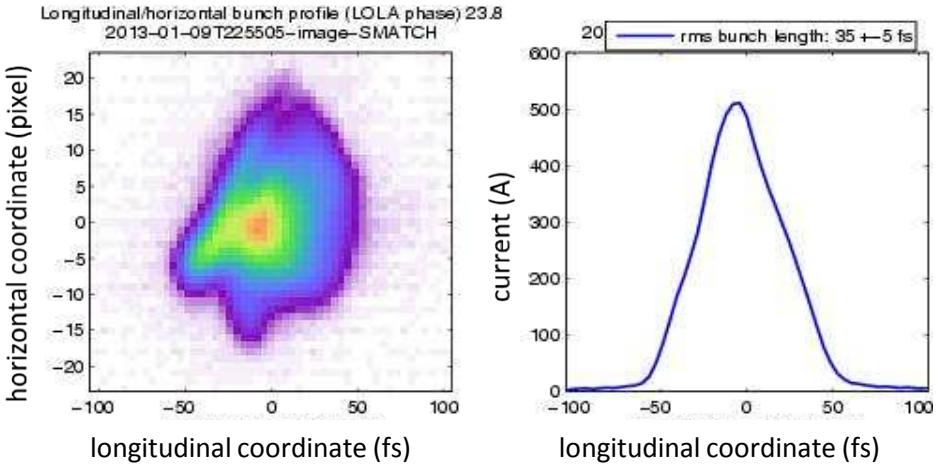
Stretcher
0.7 – 1.7 ps (rms)

Operation of FLASH with Short SASE-FEL Radiation Pulses

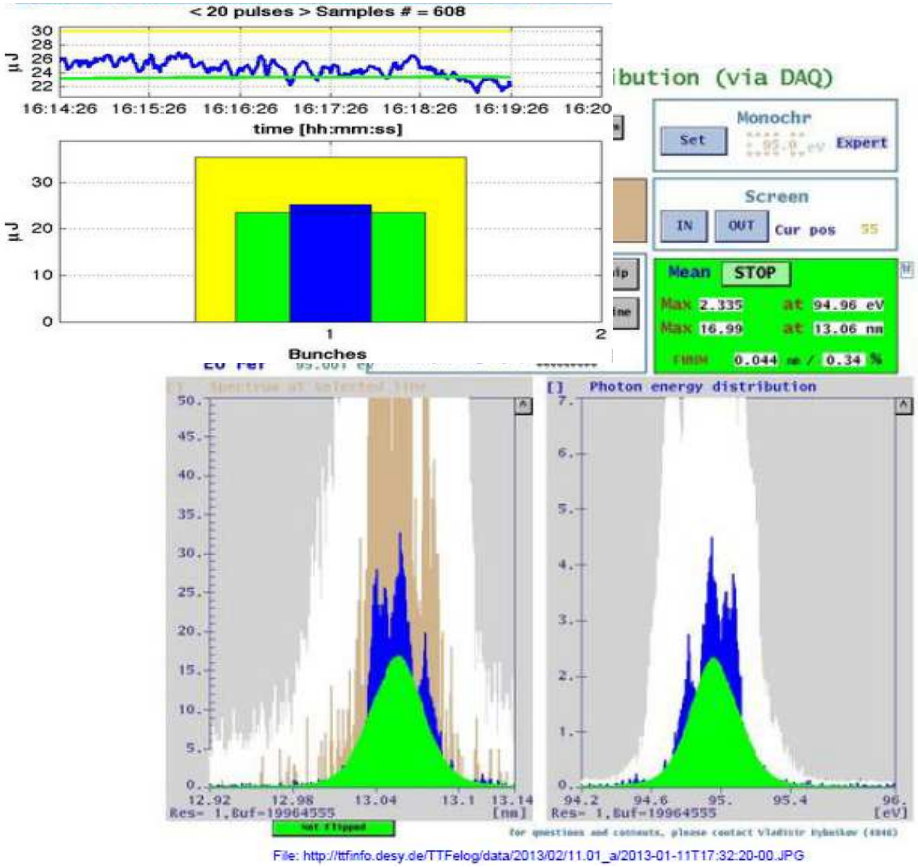
First SASE with short pulse injector laser:

- 9th & 11th of January 2013
- 5 µJ at 13.5 nm, bunch charge 35 pC





- 25 µJ at 13 nm, charge 80 pC
  Narrow bandwidth (0.34 % in linear regime, 0.42% at saturation)



- Radiation pulse duration at full undulator length is estimated as 50 fs.
- rms bunch duration of lasing fraction of the electron beam: 40 fs.

Operation of FLASH with Short SASE-FEL Radiation Pulses

Measurement: May 2014

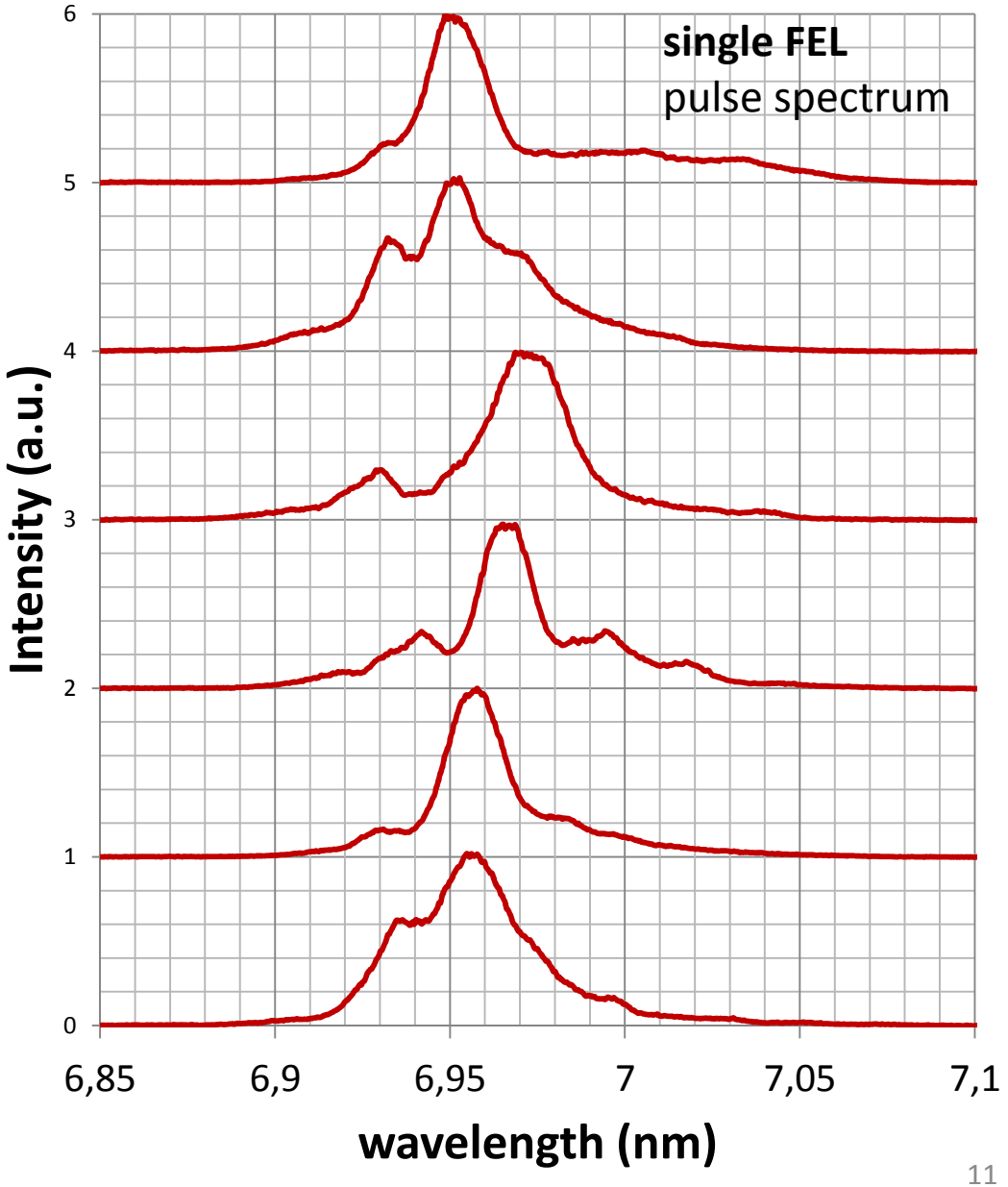
Bunch charge: 80 pC

laser pulse duration: 1 ps rms

Optical afterburner measurement of the FEL pulse duration: < 30 fs

Analysis of single FEL pulse spectrum:

- Events:1768
- λ = 6.97 nm
- in average: 3.8 spikes
- 2.7 spikes within the FWHM



Operation of FLASH with Short SASE-FEL Radiation Pulses

Measurement: May 2014

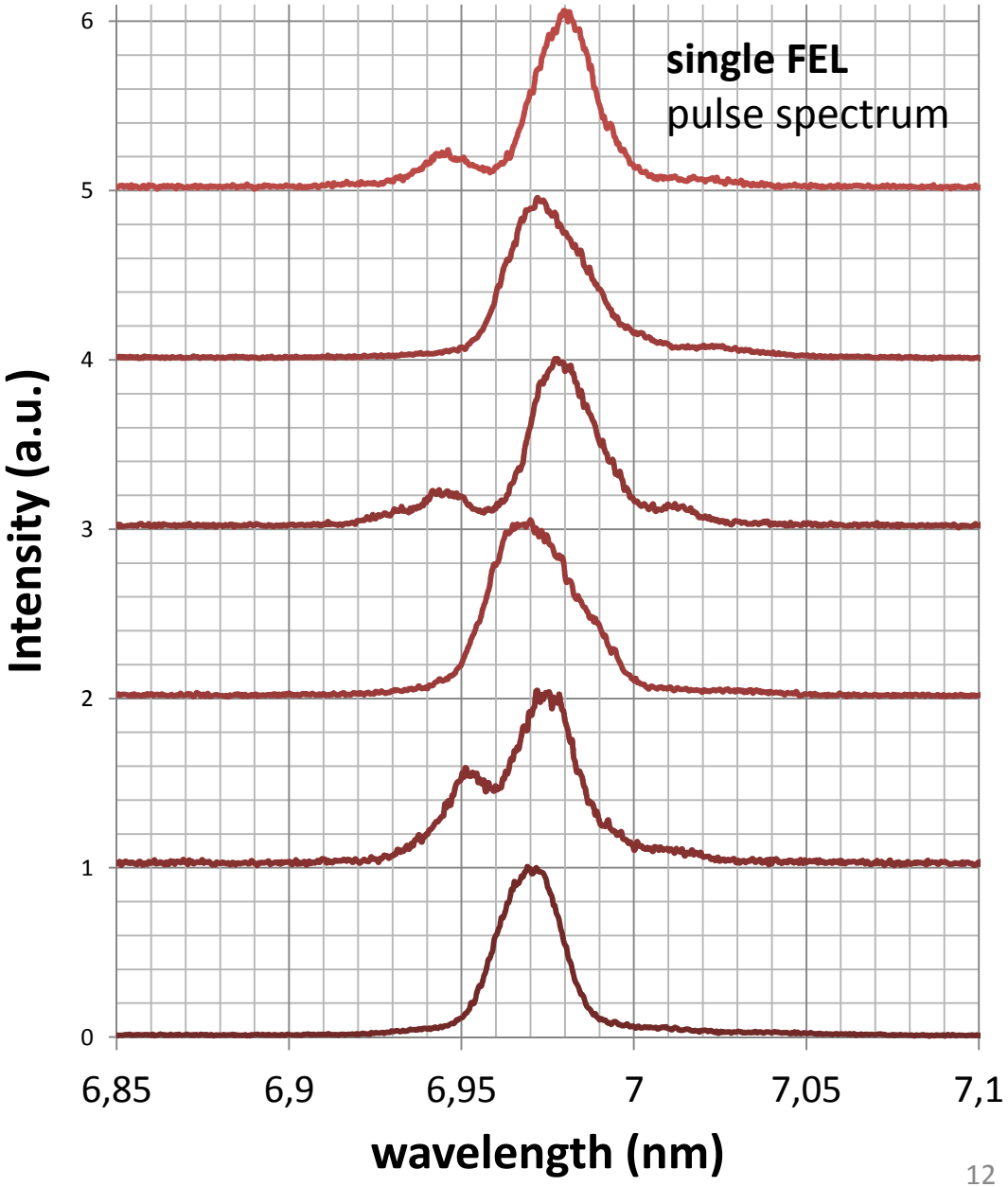
Bunch charge: 55 pC

laser pulse duration: 1 ps rms

Analysis of single FEL pulse spectrum:

- λ = 6.98 nm
- in average: 1.5 spikes within the FWHM

-> estimation of the **rms** FEL pulse duration: $\gtrsim$ 2.4 fs



Operation of FLASH with Short SASE-FEL Radiation Pulses

Conclusions

- New photoinjector laser commissioned
- FEL pulses with a few longitudinal modes demonstrated
- Outlook: truely single-spike operation
  - Needs more experience with charges of about 20 pC

Thank you for the attention

And thanks to the whole FLASH team for their support of this project.