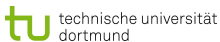


Suppression of FEL Lasing by a Seeded Microbunching Instability

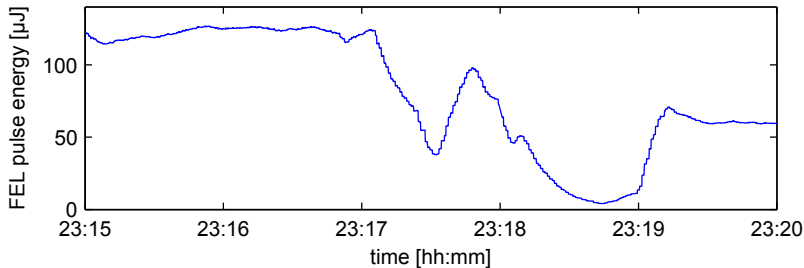
Christoph Lechner
University of Hamburg

37th Intl. Free-Electron Laser Conference
Daejeon; 25th August, 2015

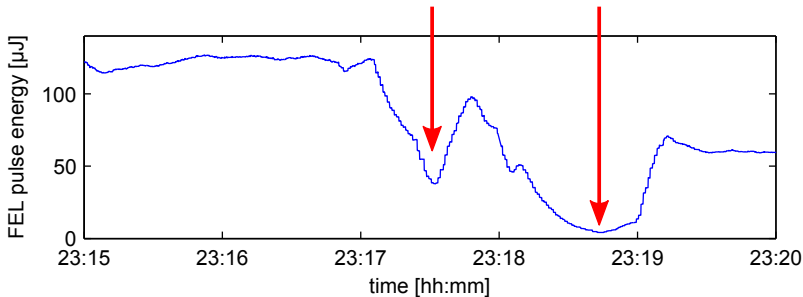


Supported by BMBF under contract No.s 05K13GU4 and 05K13PE3 and by DFG GRK 1355

Suppression of FEL Lasing



Suppression of FEL Lasing



FLASH at DESY (Hamburg)

> 3rd harmonic sc module 3.9 GHz



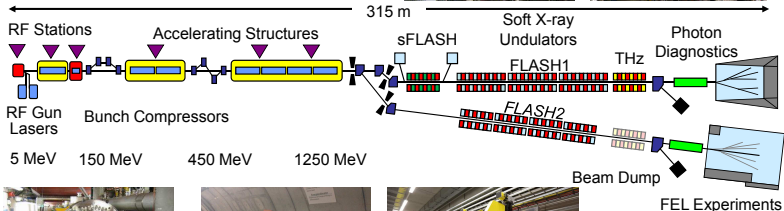
> TESLA type superconducting accelerating modules 1.3 GHz



> FLASH1 fixed gap undulators



> FLASH1 Experimental Hall



> Normal conducting 1.3 GHz RF gun
> Ce₂Te cathode
> Two Nd:YLF based ps photocathode lasers



> Extraction to FLASH2

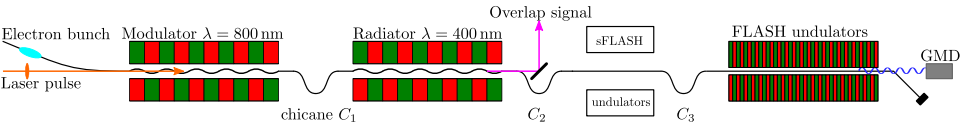


> FLASH2 variable gap undulators



> FLASH2 Experimental Hall

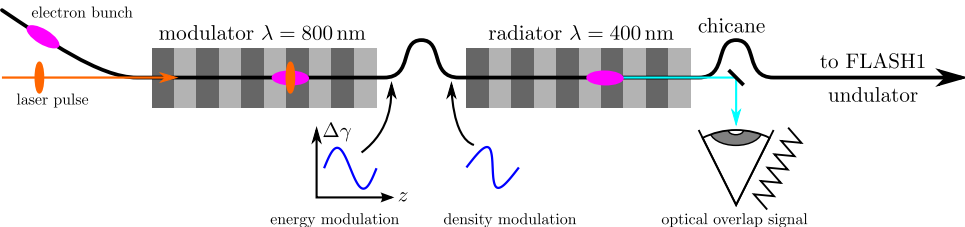
Outline



- Motivation
- Longitudinal Space-Charge Effects
- Applications

Establishing Temporal Overlap

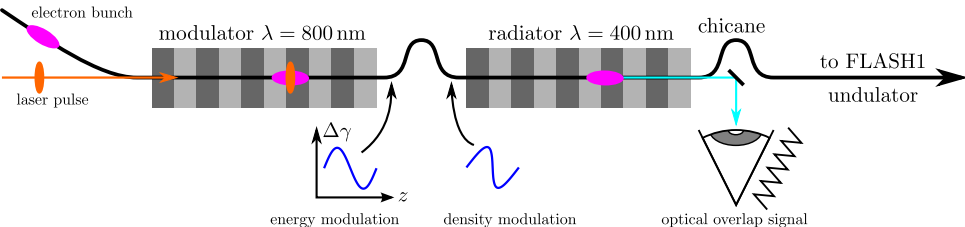
Use modulator-radiator arrangement to establish sub-picosecond laser-electron overlap



- Coherent undulator radiation emitted in radiator indicates laser-electron overlap

Establishing Temporal Overlap

Use modulator-radiator arrangement to establish sub-picosecond laser-electron overlap



- Coherent undulator radiation emitted in radiator indicates laser-electron overlap
- In coincidence with overlap, reduction of FLASH1 SASE FEL performance

LSC Amplification

- Laser pulse energy too small for direct suppression of lasing
- Amplification process required to explain results
- LSC (Longitudinal Space Charge) effects in a combination of electron beamline and chicane can amplify initial density fluctuations

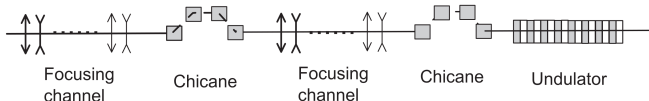
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 110701 (2010)

Using the longitudinal space charge instability for generation of vacuum ultraviolet and x-ray radiation

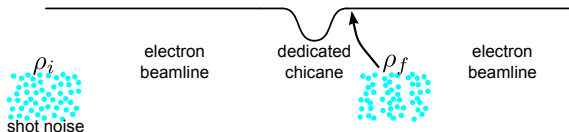
E. A. Schneidmiller and M. V. Yurkov

Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, D-22607 Hamburg, Germany

(Received 1 April 2010; published 13 November 2010)

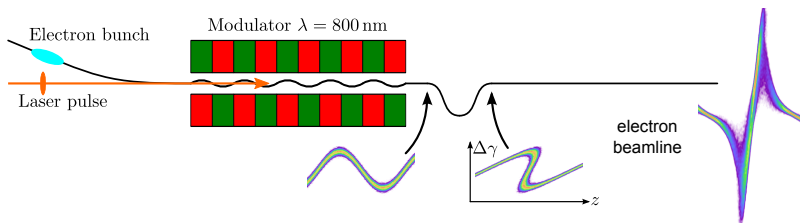


LSC Amplification



- Charge inhomogeneities generate varying longitudinal electric field
 - plasma oscillation
 - growth of energy modulation driven by field
- Chicane converts energy modulation into bunching
 - bunching after chicane can be stronger than initial bunching

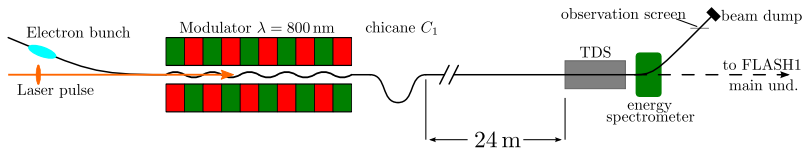
LSC Amplification



- Charge inhomogeneities generate varying longitudinal electric field
 - plasma oscillation
 - growth of energy modulation driven by field
- Chicane converts energy modulation into bunching
 - bunching after chicane can be stronger than initial bunching
- Here, LSC oscillation laser-seeded at $\lambda = 800$ nm using modulator-chicane combination

Studies of the Amplification Process

- Variation of R_{56} of chicane C_1
- Inject current-modulated electron bunch into beamline ($L = 24$ m)
- Final longitudinal phase-space distribution characterized with transverse-deflecting structure (TDS)



Parameter	Value
electron energy E_0	700 MeV
peak current I_{pk}	0.3 kA
rms bunch duration σ_t	0.3 ps
laser pulse duration	60 fs FWHM

Evolution of the Electron Bunch under Self-Fields

Simulation with code QField

Impact of Seeded LSC Effect

More than 2 MeV peak-peak

Scan of Chicane

Two laser pulse energies: 0.6 mJ and 1.2 mJ

Scan of Chicane

Result of fitting
procedure:

- initial modulation amplitude $\Delta W_0 = (185 \pm 26)$ keV
- unperturbed energy spread $\sigma_{W,0} = (105 \pm 34)$ keV (CB = 0.99)

Fitting procedure based on simulation code `QField` takes LSC effects into account

Parameters assumed in fit: peak current $I = 275$ A, normalized slice emittance $\varepsilon_n = 0.8$ mm mrad, electron beam energy $E_0 = 700$ MeV.

Some LSCA-Related Experiments

Marinelli, et al. [Phys Rev Lett 110, 264802 (2013)]

- Measured at NLCTA at SLAC
- Experiment with three-stage LSCA, starting from shot-noise
- Emission of undulator radiation
- High overall gain ($\sim 10^4$) of on-axis peak power above shot-noise level

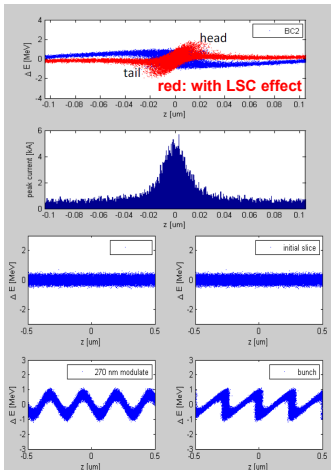
(Fig. 5 from [Marinelli, et al., PRL 110, 264802 (2013)])

Seletskiy, et al. [Phys Rev Lett 111, 034803 (2013)]:

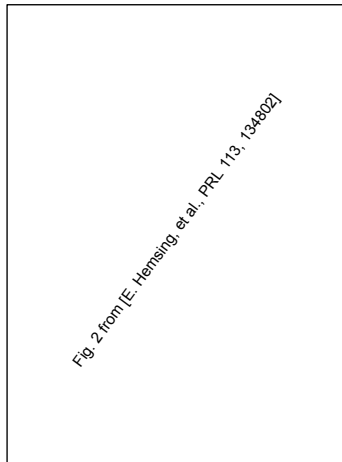
- SDL at Brookhaven
- Initial density modulation generated at photo-injector
- Strong bunching at wavelengths suitable for THz generation observed

(Fig. 3 from [Seletskiy, et al., PRL 111, 034803 (2013)])

Energy Spread Reduction in HGHG Seeding

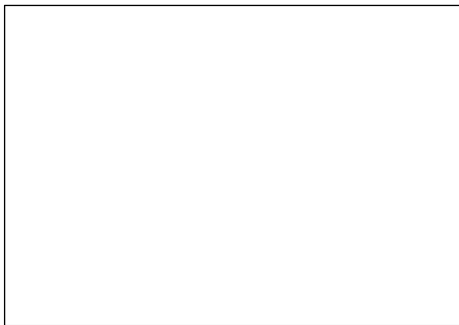


[K. Hacker, TESLA-FEL 2013-01]



[E. Hemsing, et al.,
Phys. Rev. Lett. 113, 134802 (2014)]

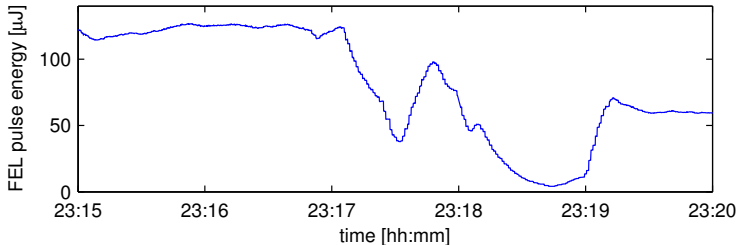
Energy Spread Reduction in HGHG Seeding



Measurement + Simulations
K. Hacker, et al., WEP031

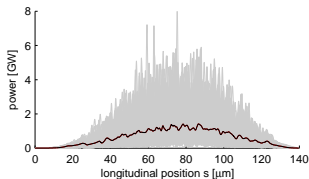
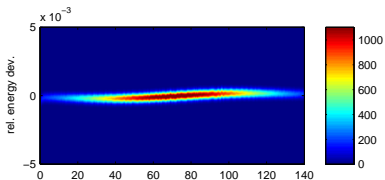
Suppression of FEL Lasing

- After studying LSC effects at 0.3 kA, we compressed the electron bunches for SASE conditions



Simulation of LSC-Assisted Suppression of FEL Lasing

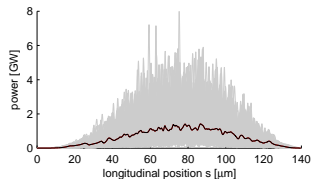
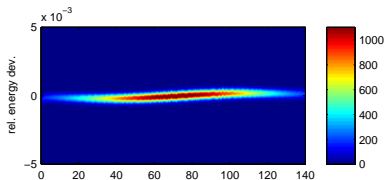
No initial laser modulation



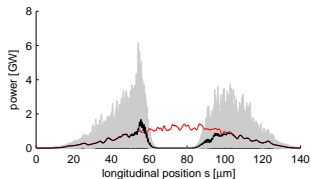
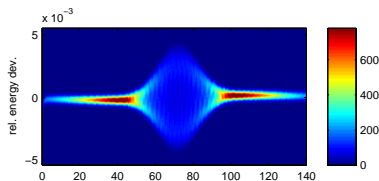
($n = 100$ GENESIS 1.3 simulation runs)

Simulation of LSC-Assisted Suppression of FEL Lasing

No initial laser modulation



$\Delta W_0 = 300 \text{ keV}$



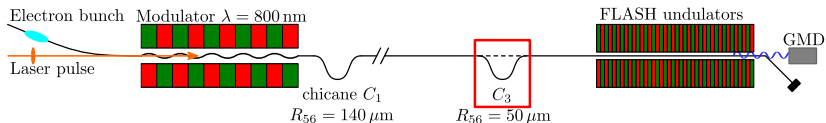
Final modulation amplitude approx.
2.5 MeV

($n = 100$ GENESIS 1.3 simulation runs)

Suppression of FEL Lasing – Measured Spectra

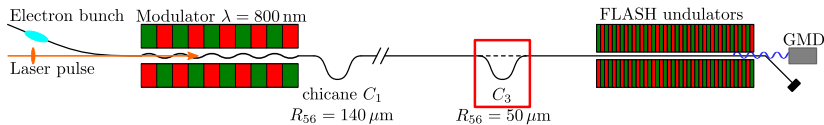
- Laser pulse duration 0.20 ps ensures reproducible initial modulation amplitude (relative temporal jitter about 60 fs rms)
- Characterization of SASE FEL radiation with high-resolution spectrometer
- FWHM of average ($n = 500$) spectrum: $\Delta\omega/\omega_0 = 0.0113$ (off), $\Delta\omega/\omega_0 = 0.0076$ (on), energy reduction by factor of 3.

Lasing Suppression: Study of Two-Stage LSCA



- In beamline after first chicane, growth of energy modulation amplitude at expense of bunching
- Chicane C_3 generates strong bunching from amplified initial modulation amplitude
- Especially for small initial energy modulation amplitudes, bunching after first chicane limited by slice energy spread

Lasing Suppression: Study of Two-Stage LSCA



Reduced impact of laser in single-stage configuration

Summary

- Hardware of FLASH1 seeding experiment is well-suited for studies of LSC processes
 - 3 chicanes, 2 modulators
 - controlled initiation of LSC oscillation
 - TDS for slice-resolved analysis
- Experimental investigation of single LSCA stage with TDS for characterization of final longitudinal phase-space distribution
- Possibility of controlled study of LSC effects in electron bunch parameter range relevant for soft x-ray FELs
- Applications:
 - Energy-spread removal in HGHG seeding
 - Suppression of FEL lasing

FLASH Seeding Posters

- MOP084: Seeded FEL Study for the Cascaded HGHG option for FLASH2
- TUP024: Simulation of the High-Gain Harmonic Generation Option at FLASH2
- WEP029: Influence of Seed Laser Wavefront Imperfections on HGHG Seeding Performance
- WEP030: HGHG seeding at FLASH - First Lasing at 38 nm
- WEP031: Measurements and Simulations of Seeded Electron Microbunches with Collective Effects

Thank you for your attention

S. Ackermann, A. Azima, C. Behrens, J. Boedewadt, G. Brenner,
M. Dohlus, M. Drescher, N. Ekanayake, R. Engel, B. Faatz, T. Golz,
K. Hacker, E. Hass, K. Honkavaara, S. Khan, T. Laarmann, L. Lazzarino,
T. Limberg, Th. Maltezopoulos, V. Miltchev, R. Molo, T. Plath,
J. Roensch-Schulenburg, J. Rossbach, E. Schneidmiller, S. Schreiber,
N. Stojanovic, M. Yan, M. Yurkov, I. Zagorodnov