Experimental Studies on FEL Gain Controlled by Laser-induced Longitudinal Space Charge Amplification

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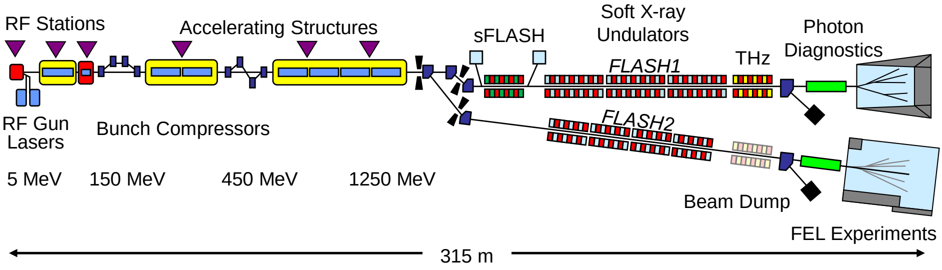
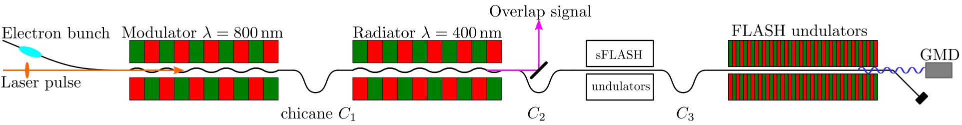
6th Microbunching Instability Workshop
Trieste; October 7, 2014

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

FLASH at DESY (Hamburg)



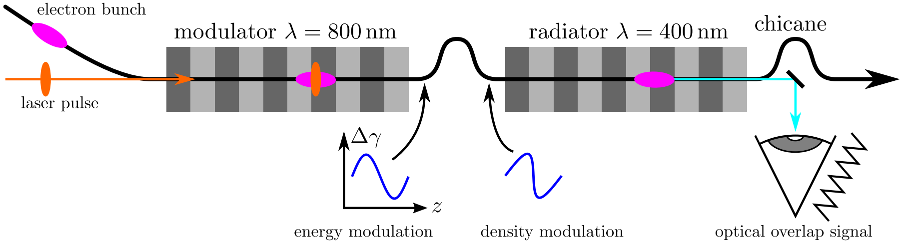
Outline



- Lasing suppression
- Longitudinal space charge amplifier (LSCA)
- Recent results

Establishing Temporal Overlap

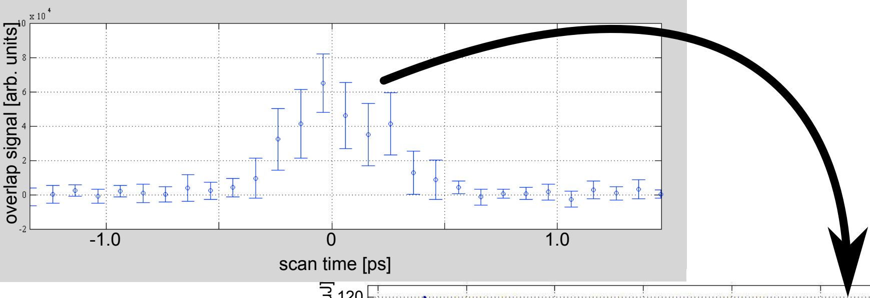
ORS technique: Use Modulator-radiator arrangement to find precise temporal overlap.



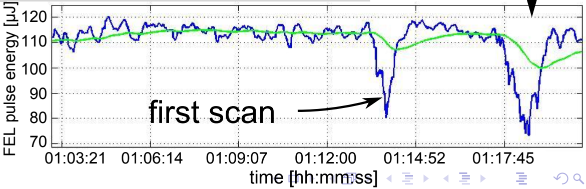
Coherent undulator radiation emitted in radiator signals laser-electron overlap.

Establishing Temporal Overlap II

Observation of coherent undulator radiation to find precise temporal overlap



ORS overlap causes drop of observed FLASH SASE energy

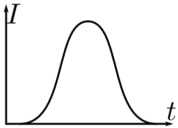


Applications of this Lasing Suppression Effect

Laser manipulation of electron bunches offers many possibilities:

Tailor electron bunches without touching machine

- short photon pulse generation in the few-fs range
- better synchronization for pump-probe experiments



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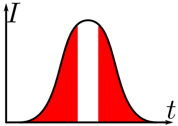

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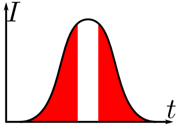
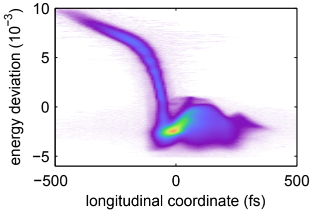


Study longitudinal profile of the electron bunches

- sample bunches longitudinally
- which part is qualified to lase?



Longitudinal phase space distribution measured with transverse deflecting structure (TDS)

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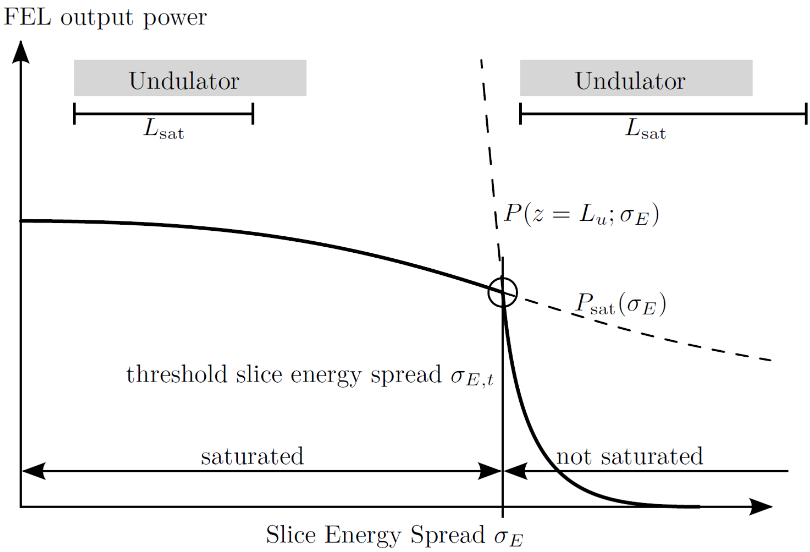
Impact of Energy Spread on FEL Performance



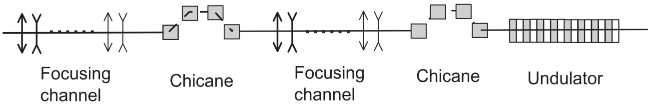
LSC Amplification

- 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 focusing channel and chicane can amplify initial density fluctuations

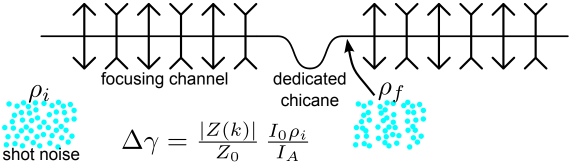
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 110701 (2010)

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)

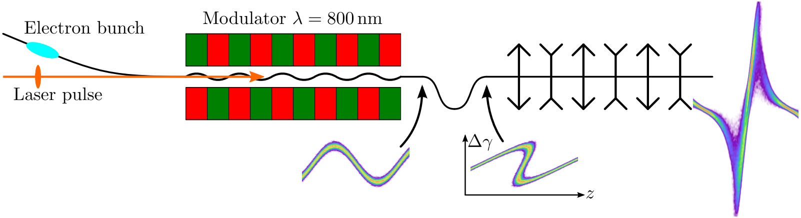


LSC Amplification



- In focusing channel, charge inhomogeneities generate varying longitudinal electric field
  - $\rightarrow$ plasma oscillation
  - $\rightarrow$ growth of energy modulation driven by field
- Chicane converts energy modulation into bunching
  - $\rightarrow$ bunching after chicane can be stronger than initial bunching

LSC Amplification



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- Here, LSC laser-initiated at $\lambda = 800\,\mathrm{nm}$ using modulator-chicane combination

Some LSCA-Related Experiments

Marinelli, et al. [5th MBI WS; Phys Rev Lett 110, 264802 (2013)]

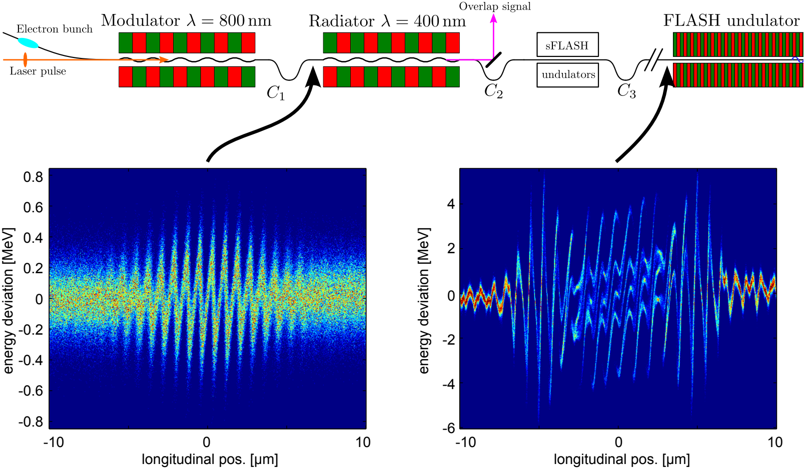
- Measured at NLCTA at SLAC
- Experiment with three-stage LSCA, starting from shot-noise
- Emission of undulator radiation
- High overall gain ($\sim 10^4$)

Seletskiy, et al. [X. Yang, this workshop; 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) removed]

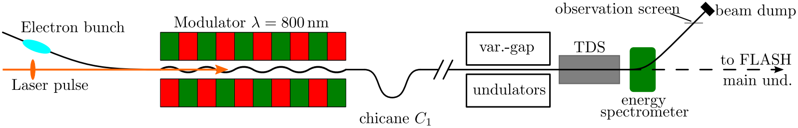
LSCA Simulations



Simulation: M. Dohlus

Studies of the Amplification Process

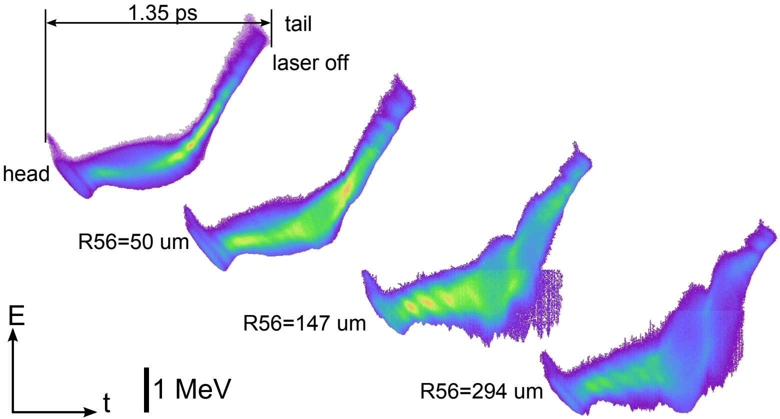
- Variation of R_{56} of first chicane (second chicane was set to $R_{56} = 40\,\mu\mathrm{m}$, third chicane off)
- Inject density-modulated electron bunch into beamline ($L = 24\,\mathrm{m}$ from chicane to TDS)
- Impact of initial modulation on electron bunches studied on LOLA transverse deflecting structure (TDS)



Parameter	Value
electron energy E_0	$700\,\mathrm{MeV}$
peak current I_{pk}	$0.3\,\mathrm{kA}$
rms bunch duration σ_t	$0.3\,\mathrm{ps}$
laser pulse duration	$200\,\mathrm{fs}$ FWHM

Measured Effect of Seeded LSC

200 fs long laser pulses



Scan of R_{56}

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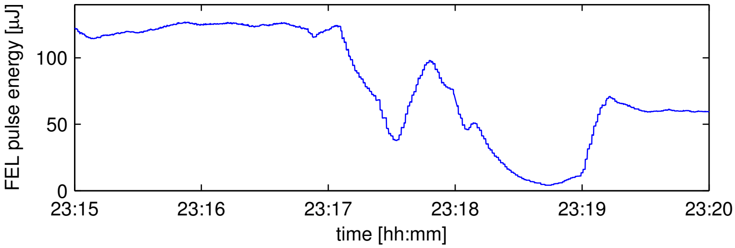
In the limit of large gain, we expect $\sigma_{E,\mathrm{tot}} \sim |R_{56}|$

$$\sigma_{E,\mathrm{tot}} = \sqrt{\sigma^2_{E,\mathrm{LSCA}} + \sigma^2_{E,0} + \sigma^2_{E,\mathrm{PW}}}$$

60 fs FWHM laser pulses

Lasing Suppression

- After studying LSC at $0.3\,\mathrm{kA}$, we compressed electron bunch for SASE conditions ($I_{\mathrm{pk}} \simeq 0.9\,\mathrm{kA}$)
- Laser pulse duration $200\,\mathrm{fs}$: stable temporal overlap



Lasing Suppression: Spectra

- Laser modulation enabled/disabled every few seconds
  $\rightarrow$ impact of any drifts removed
- 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.

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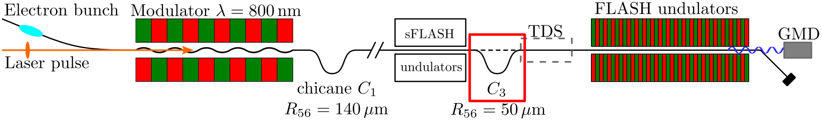
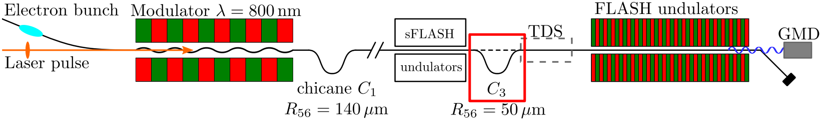
Lasing Suppression: Study of Two-Stage LSCA



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

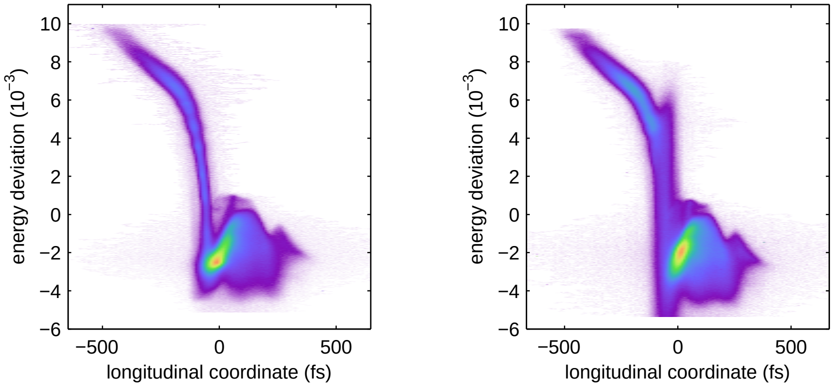
Lasing Suppression: Study of Two-Stage LSCA



[figure removed]

Reduced impact of laser in single-stage configuration

Where do we hit the Bunch?



For the relative timing with maximum SASE suppression effect, determine position of laser modulation using TDS

Summary

- Hardware of FLASH1 seeding experiment is well-suited for studies of longitudinal space charge amplification
  - 3 chicanes, 2 modulators
  - controlled initiation of LSCA
  - TDS for slice-resolved analysis

- Experimental investigation of single LSCA stage using TDS to characterize final longitudinal phase space distribution
- We used this laser-initiated instability to suppress FEL lasing process
- Stronger lasing suppression in two-stage LSCA configuration

- Implications of LSC forces on seeded operation: next presentation

Thank you for your attention

S. Ackermann, A. Azima, C. Behrens, J. Boedewadt, G. Brenner, M. Dohlus, M. Drescher, N. Ekanayake, 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