A scheme for stabilization of output power of an X-ray SASE FEL

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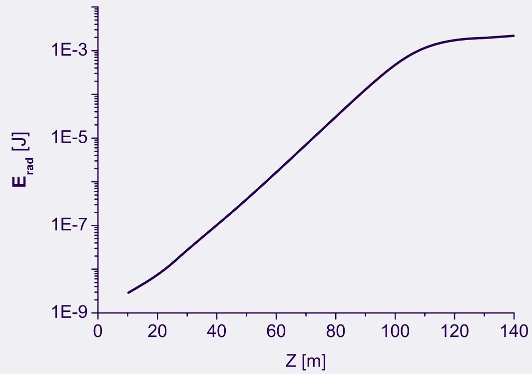
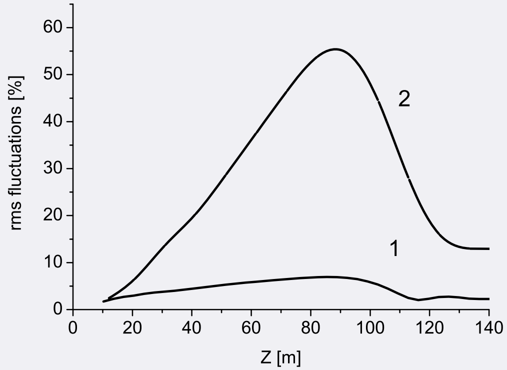
DESY, Hamburg

Stability of SASE FEL pulse energy

European XFEL: SASE1 at 1 Å





Exponential amplification, “controlled instability”

$$P \propto \exp(2z / L_g)$$

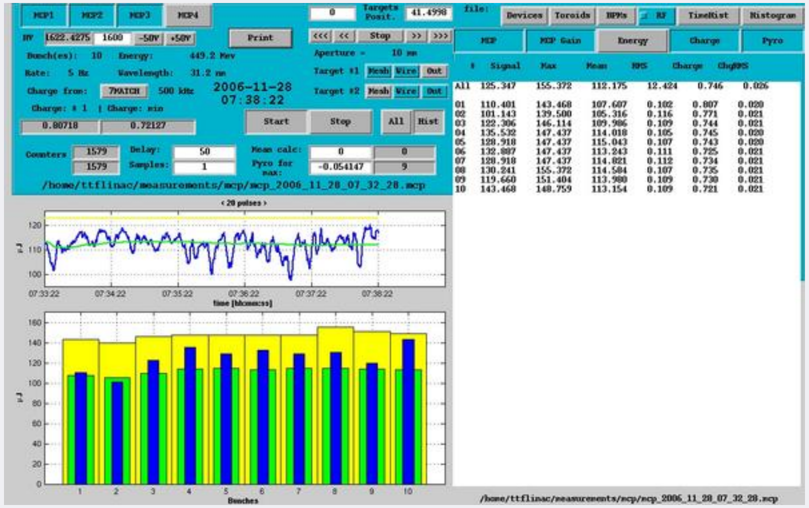
$$L_g \propto \frac{\varepsilon_n^{5/6}}{I^{1/2}}$$

Curve 1: intrinsic fluctuations $\propto \sqrt{l_{coh} / \sigma_z}$

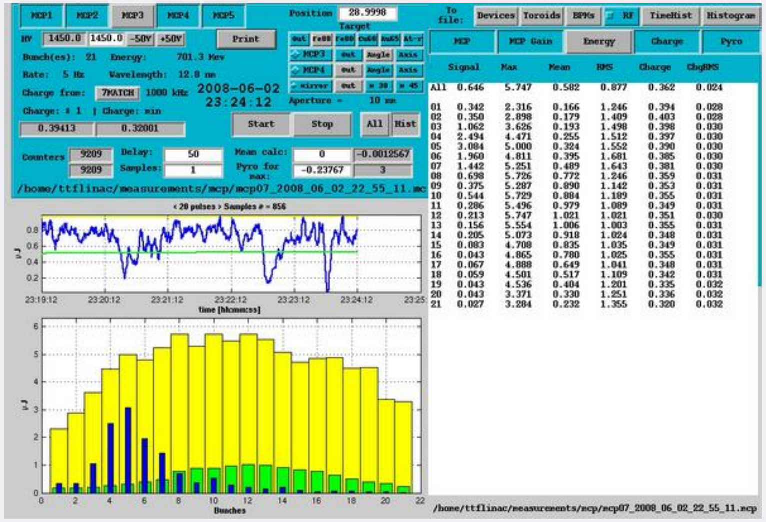
Curve 2: due to 10% variations of current (bunch compression factor)

Saturation helps but …

Examples from FLASH operation



Bunch number in the train



Bunch number in the train

Saturation, 10% fluctuations

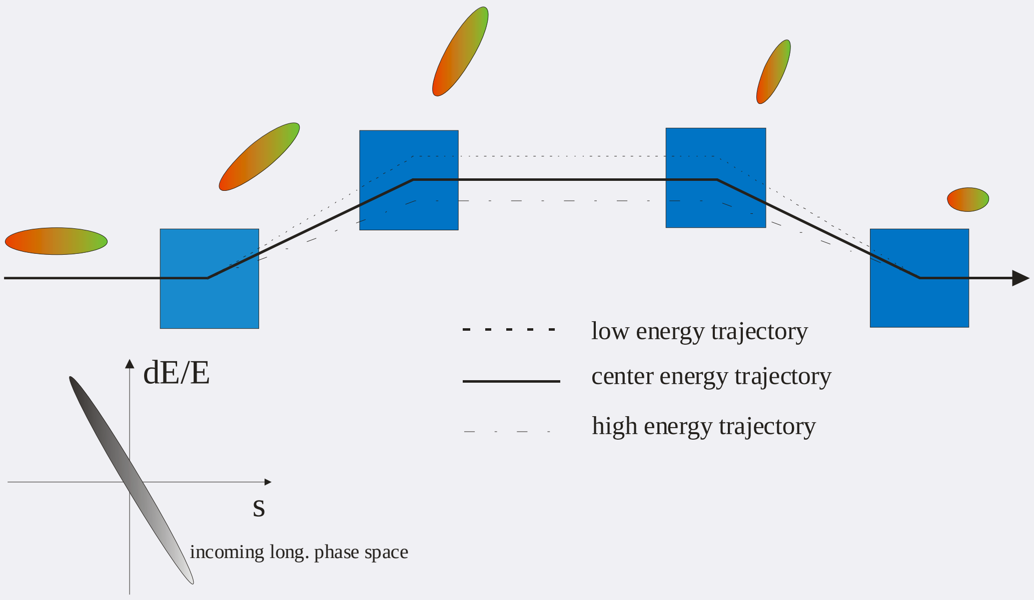
Exp. gain, less stable machine, >100% fluctuations

Difficult to tune SASE!

Multibunch SASE signal (μJ) recorded with MCP detector

- max
- single
- average

Bunch compression (linearized)



$\delta = \Delta E / E_0$, R_{56} - "longitudinal dispersion"

Compression factor :

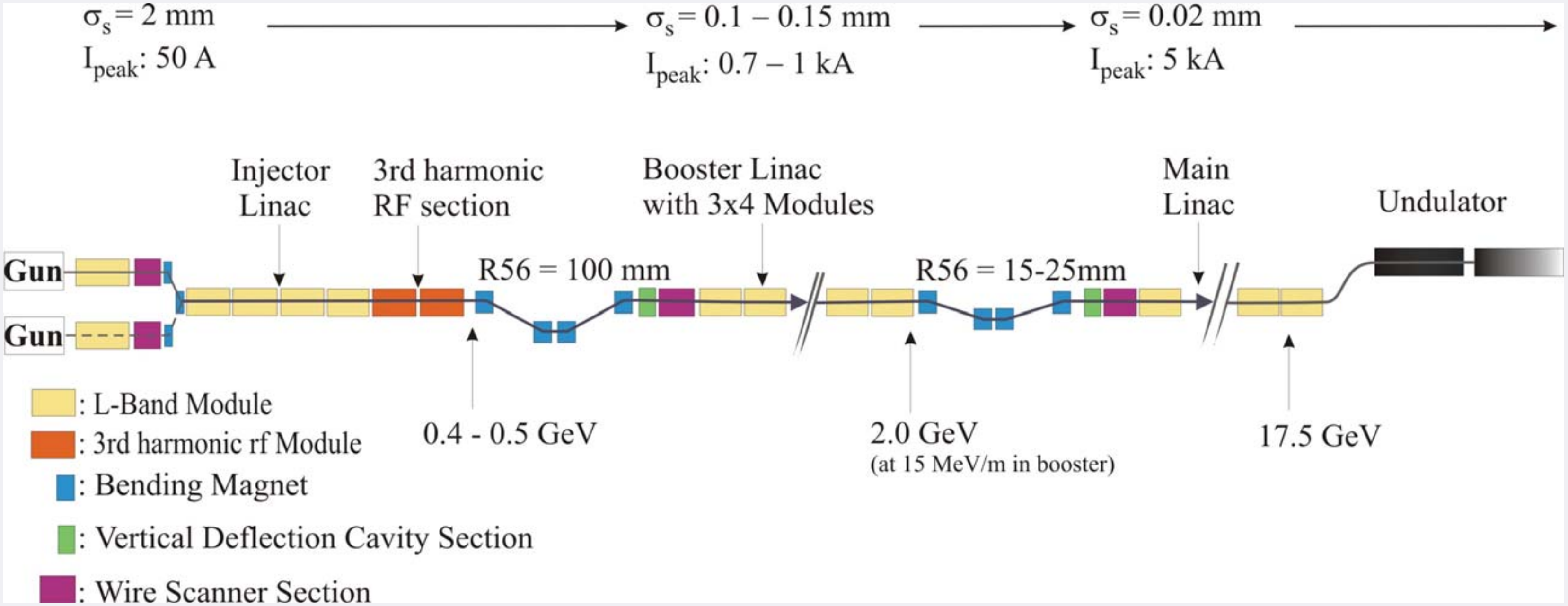
$$C = \frac{1}{1 + R_{56} \frac{d\delta}{ds}} \qquad R_{56} > 0, \quad \frac{d\delta}{ds} < 0$$

Small variations :

$$\frac{\Delta C}{C} \propto C \Delta\varphi$$

The larger the compression factor, the tighter the tolerances

Two-stage compression for the European XFEL



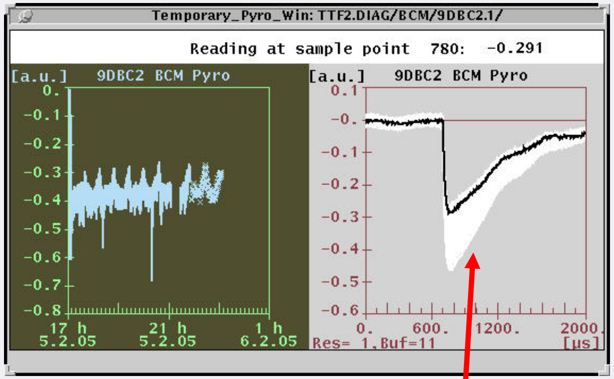
C=100

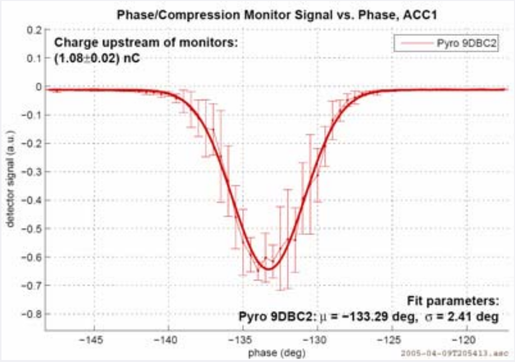
Tolerances are tight:

(a few) 0.01 degree for phases

(a few) 10^{-4} for amplitudes

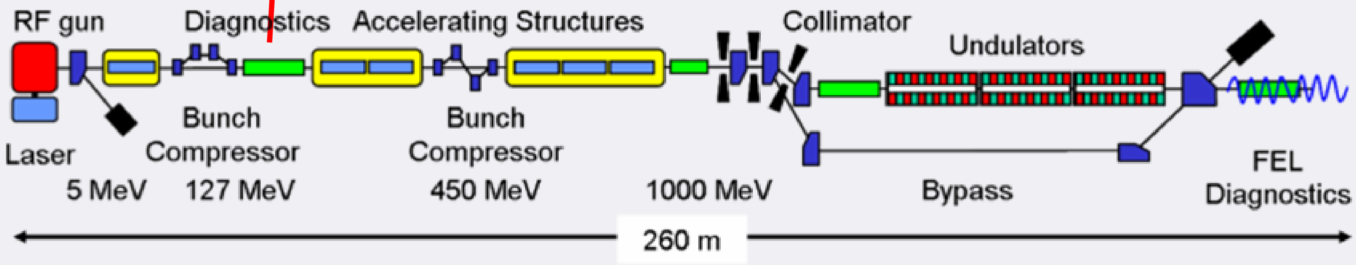
Slow drifts and jitters of RF parameters





Beam-based slow feedback at FLASH:

Intensity of coherent diffraction radiation of compressed bunches is measured; phase of ACC1 is regulated

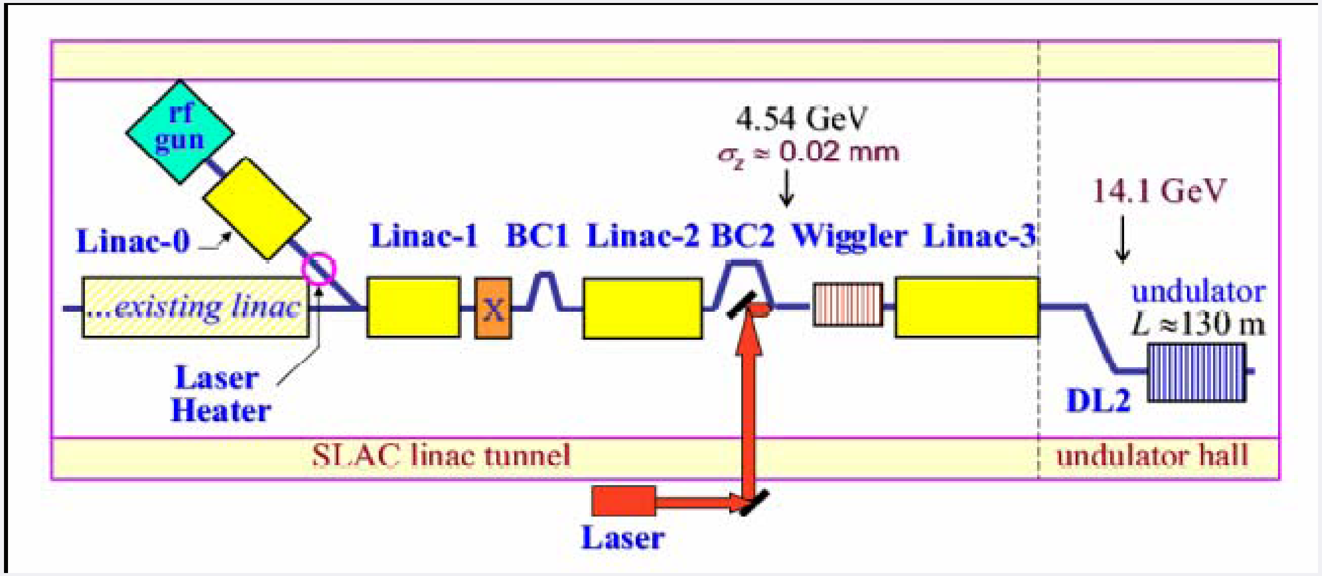


Pulse-to-pulse variations (jitters) cannot be compensated in this way

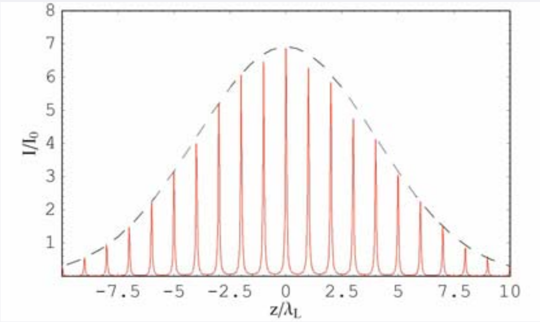
Develop single-bunch feedback;
make use of collective fields of each individual bunch

Current-enhanced SASE

A. Zholents et al., Proc. of FEL'04 Conf.

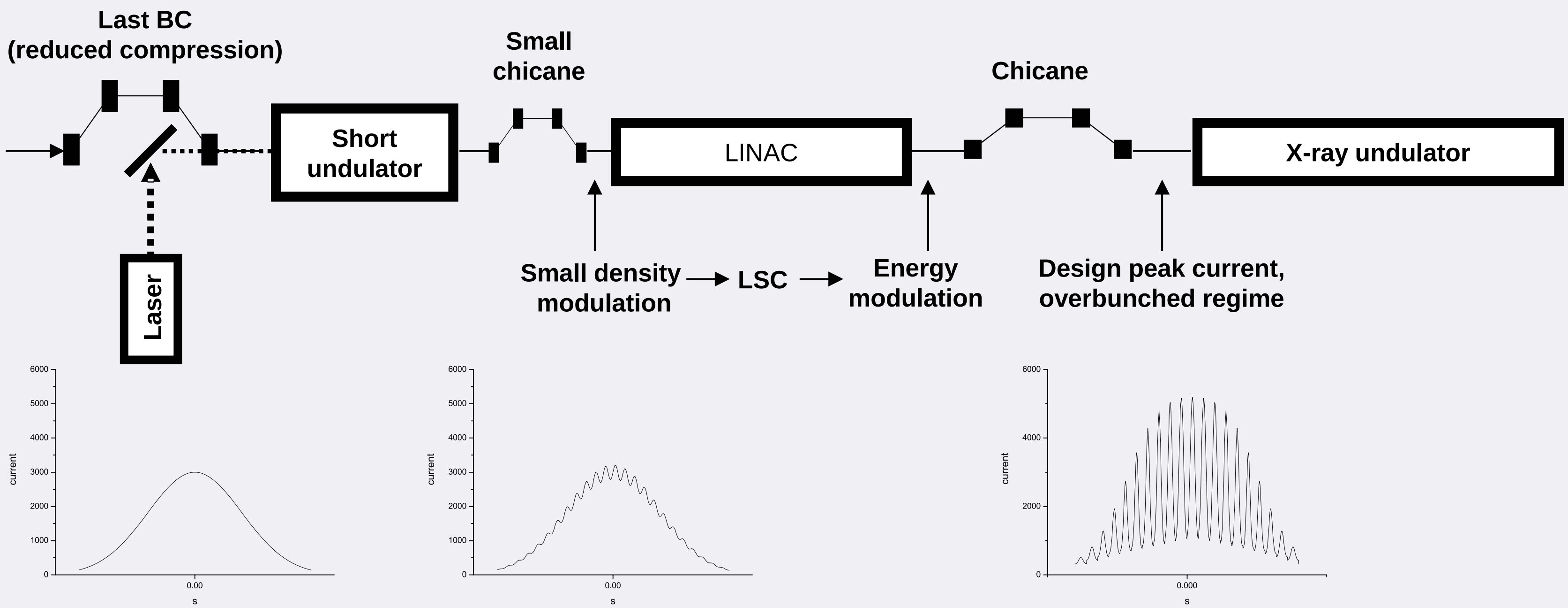


Width of current spikes is comparable to (or larger than) FEL coherence length



Alternative way of compression: small R_{56}, CSR is strongly suppressed due to R_{51}

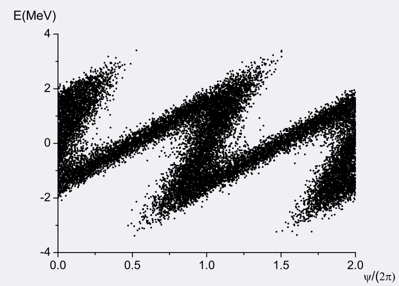
Stabilization scheme



larger C → stronger longitudinal space charge (LSC)

→ larger energy modulation → stronger overbunching

→ smaller enhancement of current



Longitudinal Space Charge (LSC)

- The most simple and robust collective effect

- Can be safely calculated

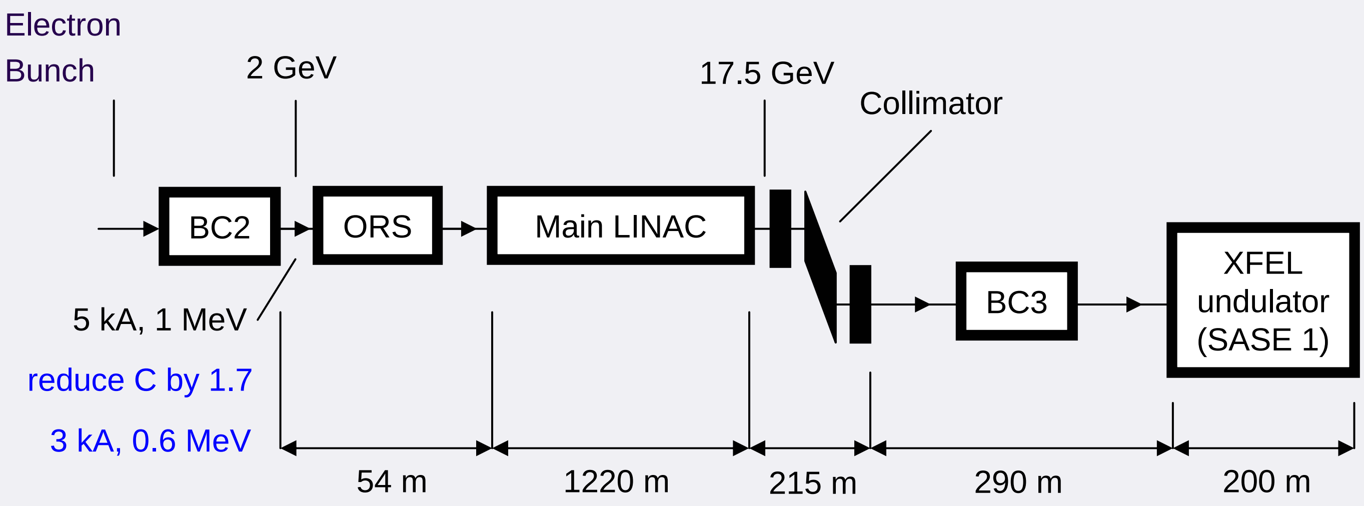
- Sufficiently strong for short wavelength

$$\sigma_{\perp} << \frac{\gamma\lambda}{2\pi} << b$$

$$Z \propto \frac{\ln(\gamma\lambda / 2\pi\sigma_{\perp})}{\lambda\gamma^2}$$

"pencil" beam, free space

Application to European XFEL



ORS: Optical Replica Synthesizer , being commissioned at FLASH , poster TUPC114 (Gergana Angelova)

Ti:S laser (800 nm), a few MW, energy modulation 100 keV, density modulation 5%

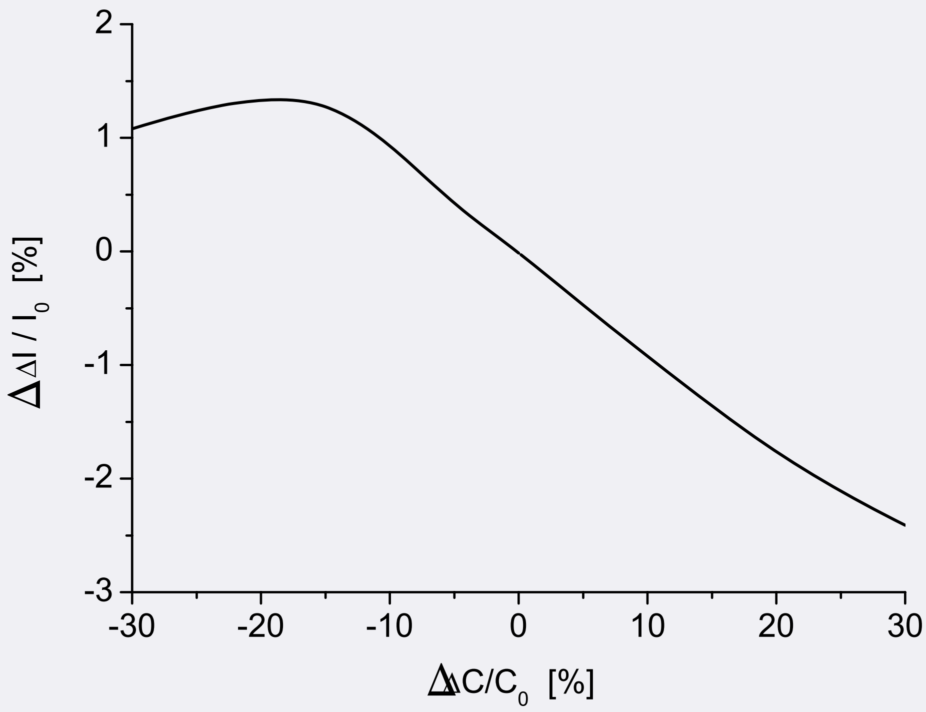
LSC: energy modulation 1.6 MeV

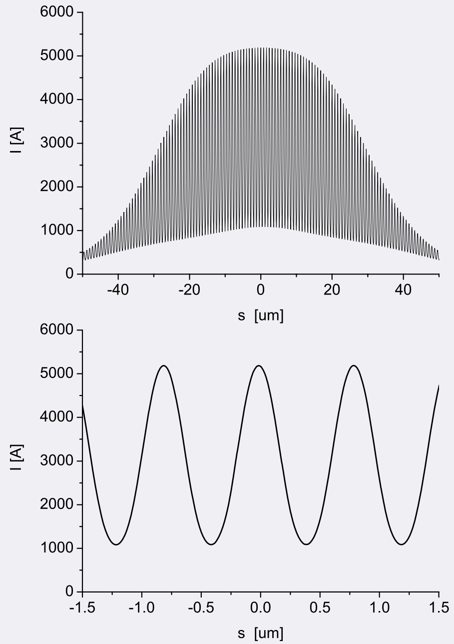
BC3: R56 is 3 mm

Stability of peak current

Model of linearly compressed Gaussian bunch

Semi-analytical calculations of longitudinal dynamics from ORS through BC3

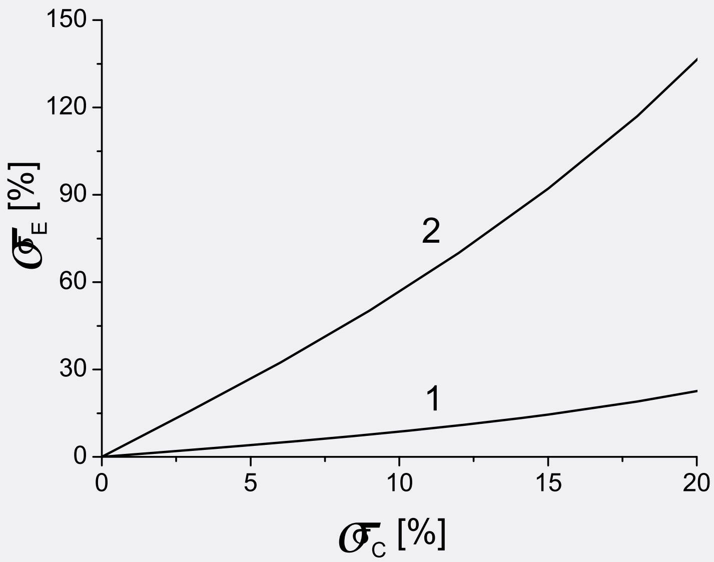




Variation of peak current (BC3) versus variation of compression factor (BC2)

FEL simulations

FEL code FAST, 1-D version, LSC after BC3 included



FEL properties:

-the same saturation length

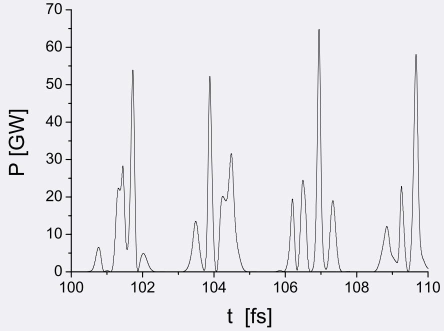
(can be reduced if current is enhanced)

-pulse energy is reduced by 30%

(can be increased if current is enhanced)

-the same bandwidth

-pulse structure is different



Fluctuations of FEL pulse energy versus fluctuations of compression factor

Position along the undulator 90 m (strongest fluctuations)

Intrinsic fluctuations excluded

Curve 1: stabilization scheme applied, curve 2: standard compression

Stabilization factor

For the same variations of compression factor, the fluctuations of SASE pulse energy are reduced by a factor 6 when the scheme is applied. Since compression is reduced by a factor 1.7, SASE fluctuations are reduced by a factor 10 for the same RF jitters.

Alternatively, aiming at the same level of SASE fluctuations, one can loosen RF tolerances by an order of magnitude.

Other options

Current enhancement is easily possible (for instance, just by increasing compression factor in the main compression system back to its original value, and/or by changing parameters of the optically modulated beam and the chicane). Stabilization effect would then be reduced.

Important: laser power is strongly reduced - the job is done by LSC!

Realization of the scheme would automatically allow to use a method for timing an XFEL source to high-power laser (poster THPC157 by G. Geloni).