Attosecond soft X-ray pulses from a longitudinal space charge amplifier at FLASH

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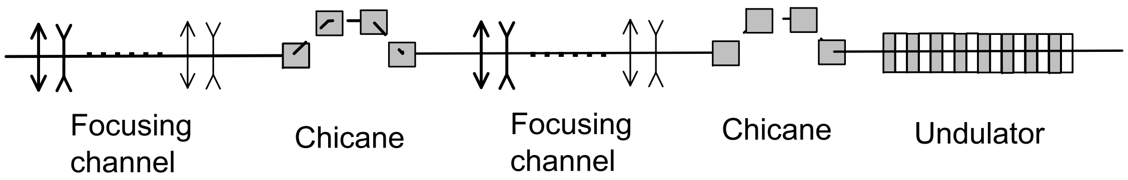
Longitudinal Space Charge Amplifier (LSCA)

The concept is based on the predicted and observed LSC instability in linacs with bunch compressors.



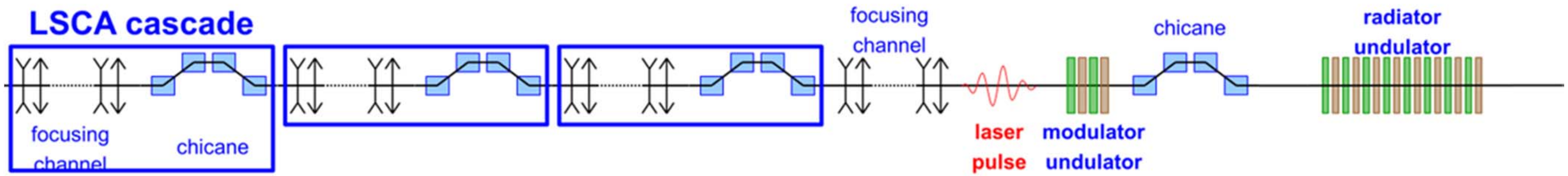
$$\lambda_0 \simeq 2\pi\sigma_\perp/\gamma$$

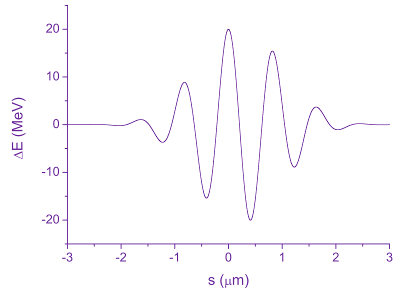
It was proposed to operate LSCA in VUV and X-ray ranges, basic scaling relations were formulated, possible applications are identified:

- cheap addition to the existing or planned XFEL facilities: extension towards longer wavelength, production of the second color for PP experiments, generation of broadband radiation
- generation of attosecond pulses (option is supported by broadband nature of the amplifier)
- because of robustness it might be a good concept of a light source based on laser-plasma accelerators

E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 13(2010)110701

LSCA-based attosecond scheme



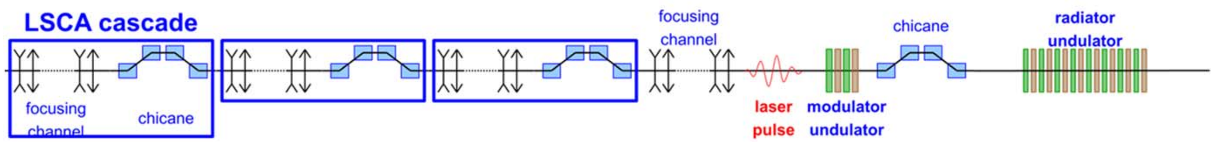


First cascades are used to amplify shot noise. In the last cascade after a drift the beam is modulated by a few-cycle laser pulse. In the last compressor (with reduced R56) a short slice is compressed: WL compression and final amplification to saturation. The radiator undulator is tuned to the compressed WL.

E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 13(2010)110701

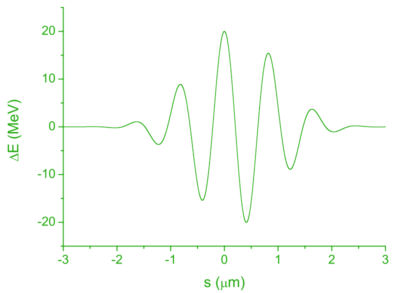
M. Dohlus, E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 14(2011)090702

LSCA-based attosecond scheme: simulations for FLASH



Electron beam parameters

Energy	1.2 GeV
Charge	100 pC
Peak current	1 kA
Slice energy spread	150 keV
Slice emittance	0.4 mm mrad



from S2E simulations (Dohlus&Zagorodnov)

FODO period and beta = 1.4 m; length of a drift = 2.8 m

R56 = 50 um (cascades 1-3), and 7 um (cascade 4)

Modulator undulator: 2 periods, period length 10 cm (resonance with 800 nm)

Radiator undulator: 5 periods, period length 2.5 cm

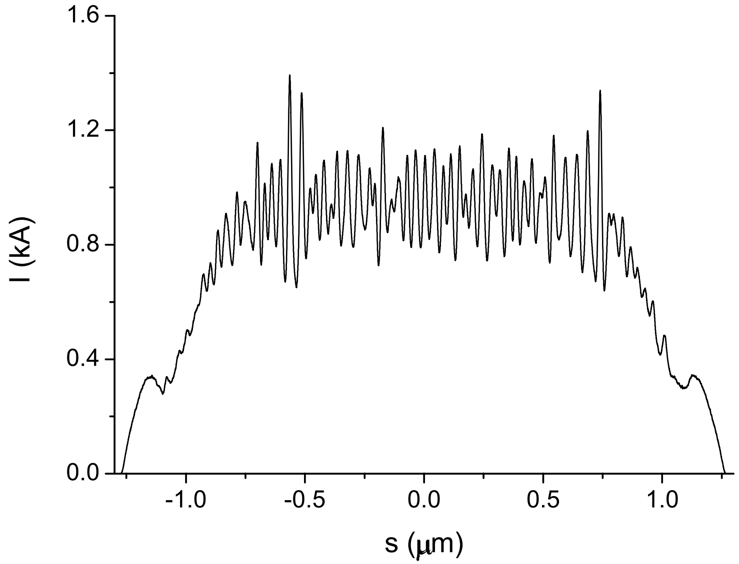
Radiator WL: 3-8 nm

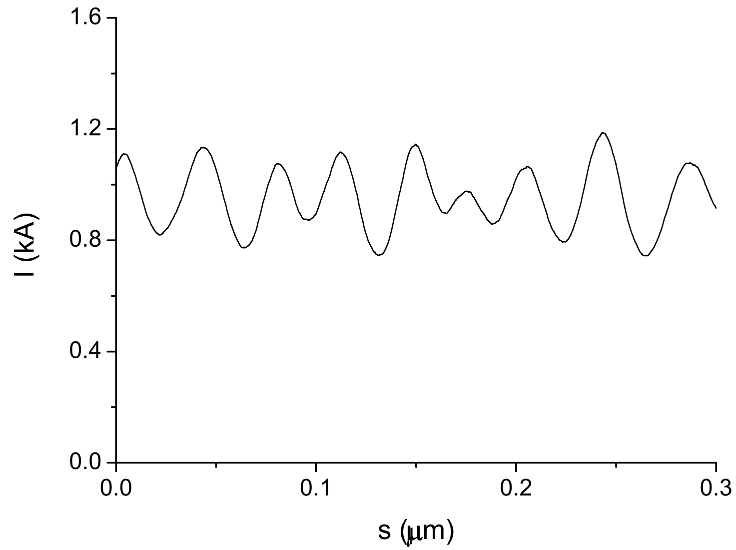
Total length: 14 m

M. Dohlus, E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 14(2011)090702

Three cascades simulated with Astra (3D)

Astra: 3D space charge , motion in FODO lattice, fair start-up from shot noise. Only short part of the bunch (2 um) was simulated, 40 million particles were distributed randomly in 6D phase space.

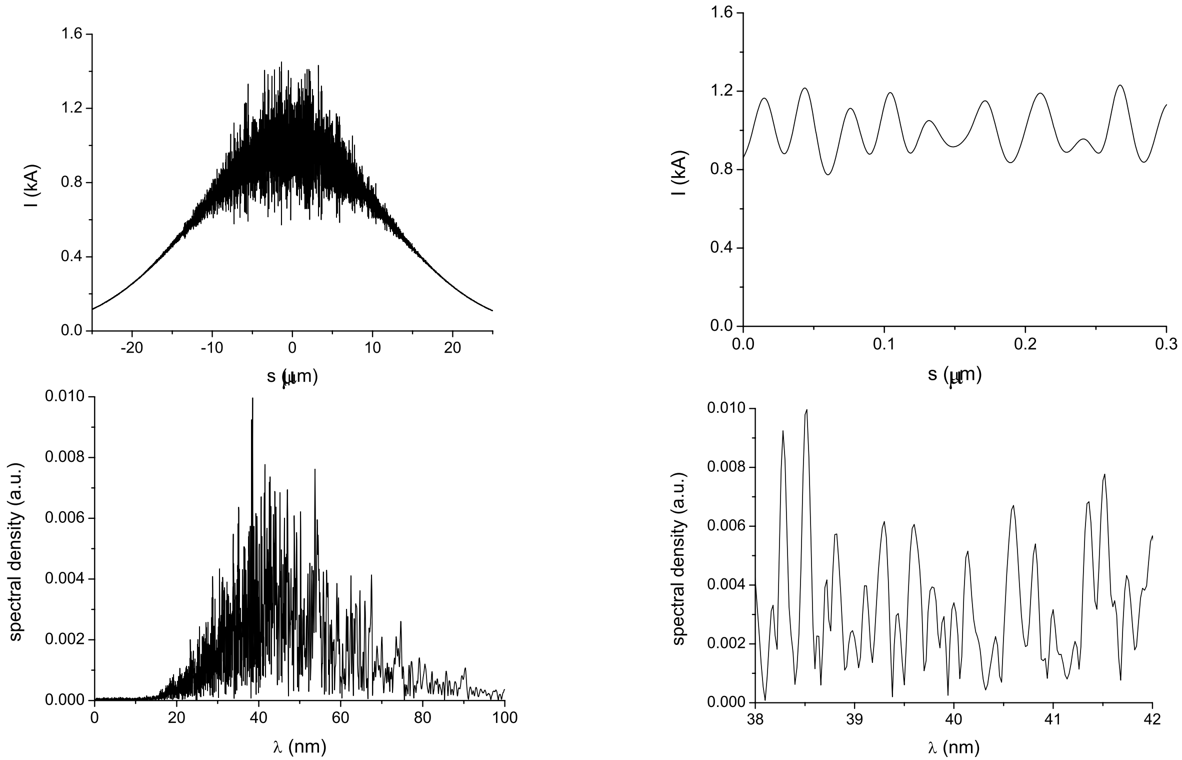




Current (full and zoomed)

Three cascades simulated with LOSCA

LOSCA: 1D LSC wake (but averaged over beam cross-section) , 1D motion. Full bunch (100 pC) simulated, 0.6 billion particles distributed randomly in phase space.

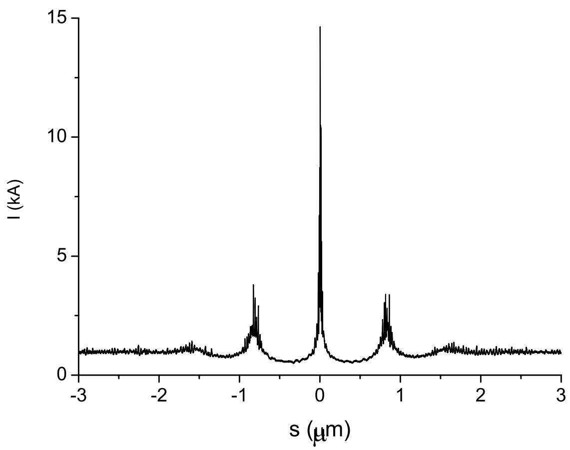


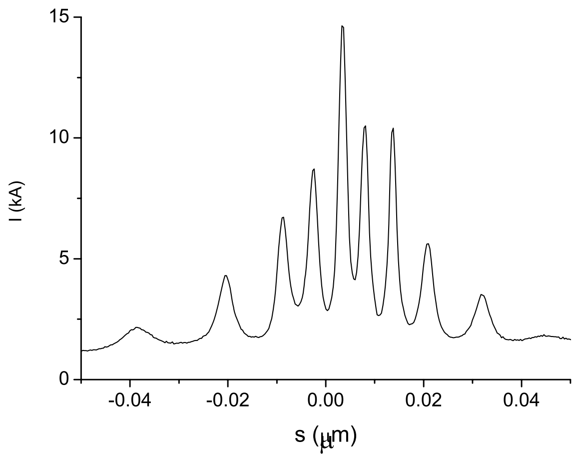
Current (full and zoomed)

Spectrum (full and zoomed)

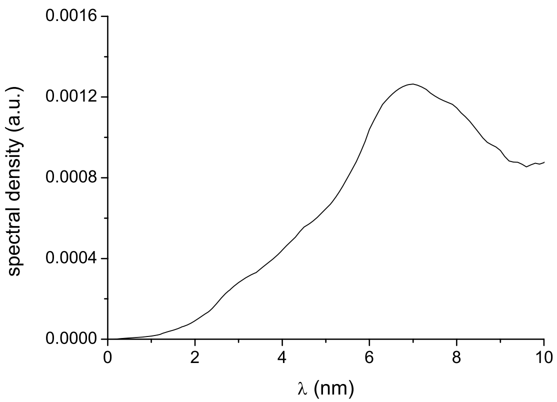
Astra and LoSCA give the same amplification of shot noise. Sampling different LSC fields during transverse motion in Astra is (to some extent) equivalent to averaging LSC wake in LOSCA

Compression in the last chicane





Current



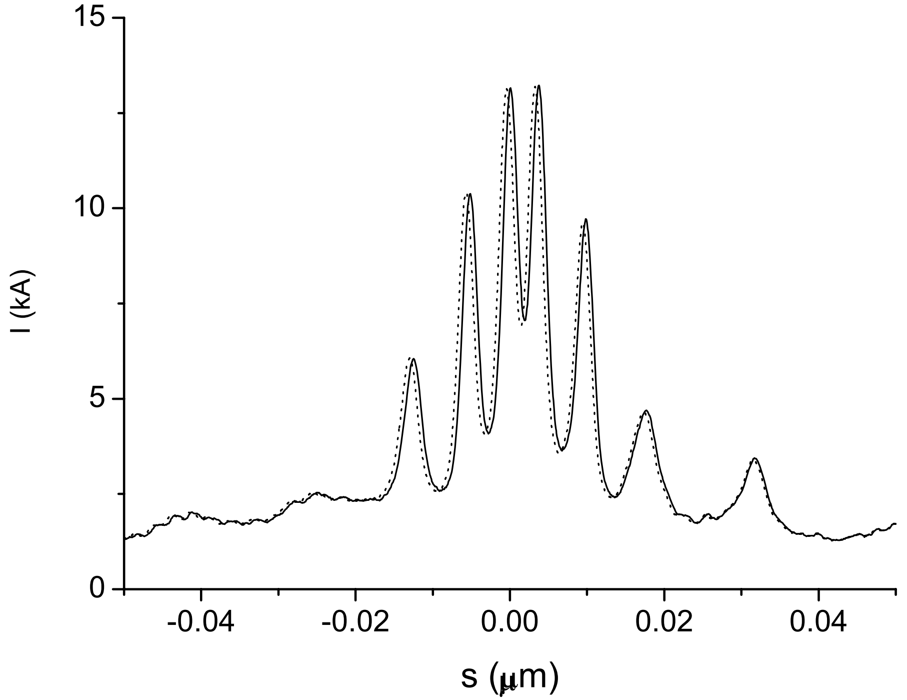
Spectrum (averaged)

Below 10 nm the spectral components are mainly coming from the main peak

Simulations of CSR in the last chicane

Distribution from Astra exported to CSRtrack, tracking through the last chicane:

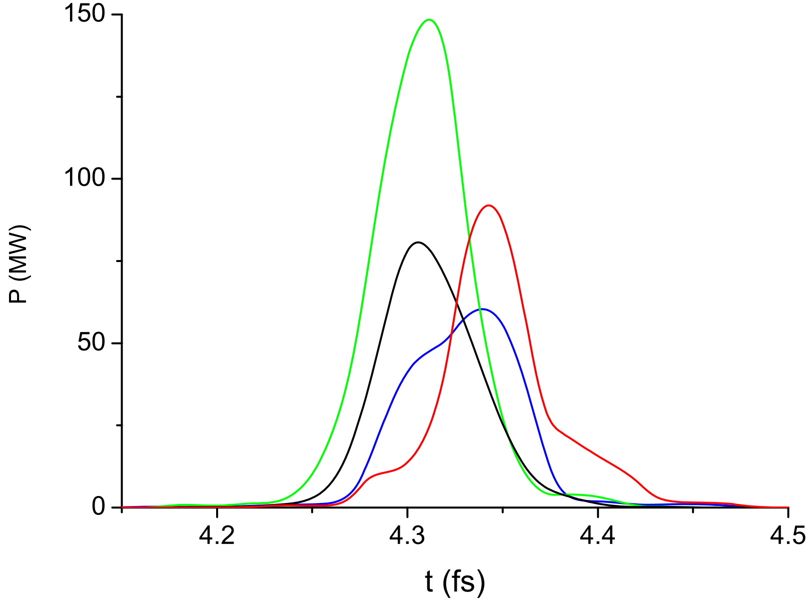
CSR off (solid) and on (dots)



No noticeable effect on transverse and longitudinal dynamics (except for a little time shift) observed. Complete smearing of microstructures (due to R51 and R52) inside chicane.

Attosecond pulses from radiator undulator

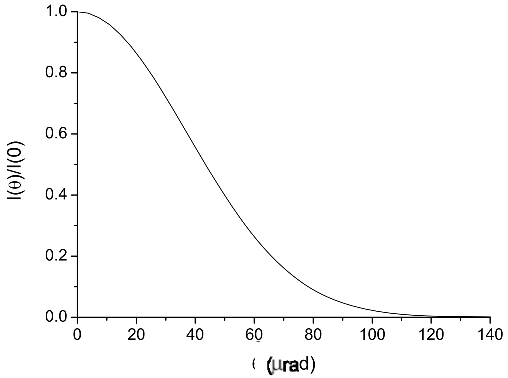
Simulations with FAST



pulse length 50-70 asec (FWHM)

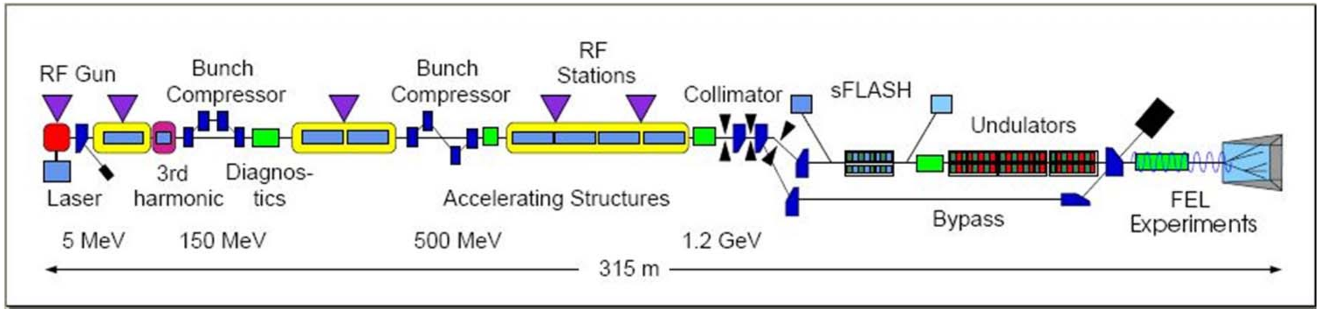
pulse energy 5 nJ

contrast above 98%



Pinhole (half-angle ~100 urad) to suppress spontaneous emission background

Possible implementation of attosecond LSCA at FLASH

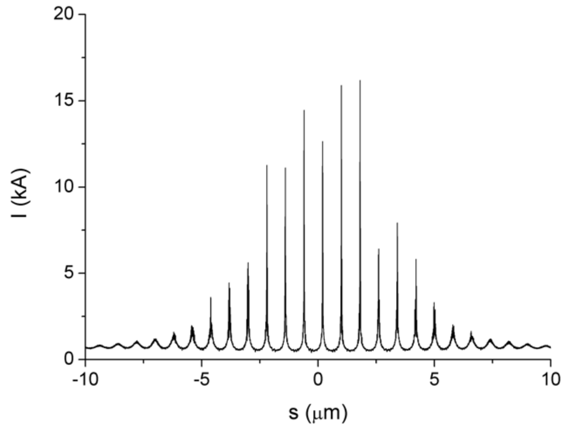


- Attosecond LSCA can substitute ORS or sFLASH
- Make use of the existing infrastructure: laser lab, laser beam transport, XUV transport, experimental hutch
- Additional hardware: ~ 20 quads, 4 chicanes (PM similar to XFEL phase shifters?),

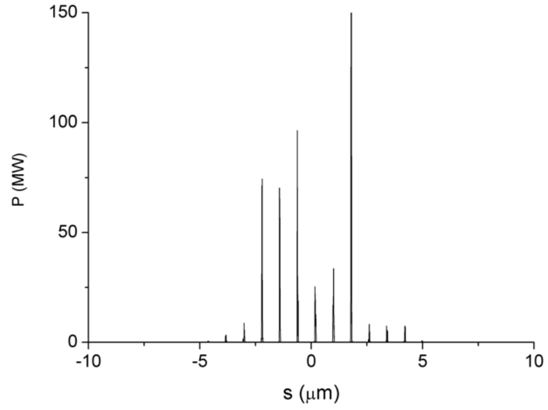
  2 short undulators (~ 10 cm), modified laser transport, diagnostics (< 1 MEuro ?)
- First stage: use existing Ti:S laser system, produce a sequence of attosecond pulses (see next slide), check validity of the concept
- Second stage: change to 5 fs long laser pulses, get an isolated attosecond X-ray pulse
- Pump-probe experiments in the experimental hutch with attosecond X-ray pulse and 5 fs long laser pulse can be possible (timing preserved?); alternatively, optical pulse can be generated (by the spike) in an additional two-period undulator and transported together with X-ray pulse
- Seeding FLASH undulator with attosecond pulse (ending up with ~ 1 fs pulse) can be considered as an option
- Implementation at FLASH II, FLASH III, … can also be discussed

Possible implementation at FLASH (first stage)

- Make use of the existing Ti:S laser system: 35 fs long pulse with up to 50 mJ
- In simulations we used only 15 mJ, got a sequence of attosecond pulses



Electron beam current



Sequence of attosecond pulses

Conclusions

- LSCA-based attosecond scheme can be implemented at FLASH in a relatively easy way
- We can test a new principle of generation of VUV and X-ray radiation. This may have a strong impact on the development of light sources (including compact sources based on laser-plasma accelerators)
- For the first time we can produce powerful soft X-ray attosecond pulses to be used in pump-probe experiments