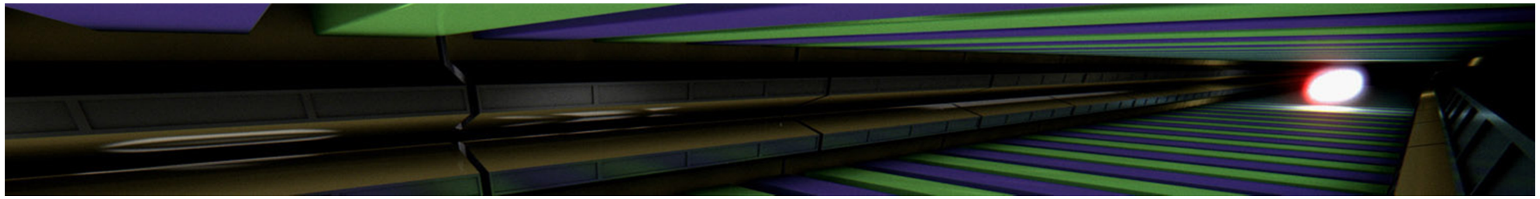
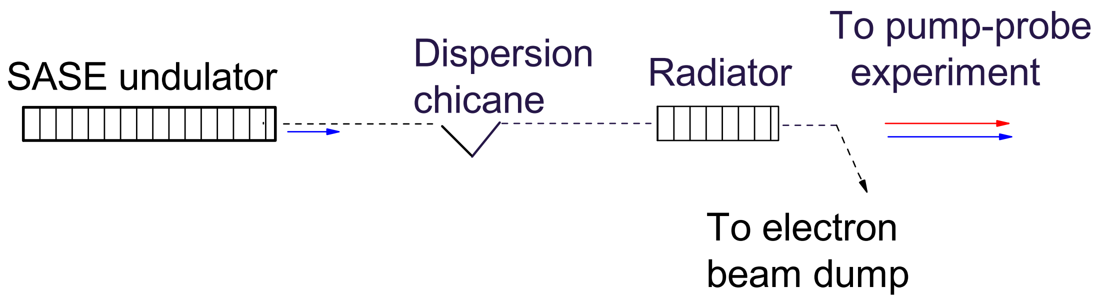


Optical afterburner for a SASE FEL: first results from FLASH

M. Gensch, E. Schneidmiller, N. Stojanovic, M. Yurkov

FEL Beam Dynamics Group Meeting, February 14, 2011

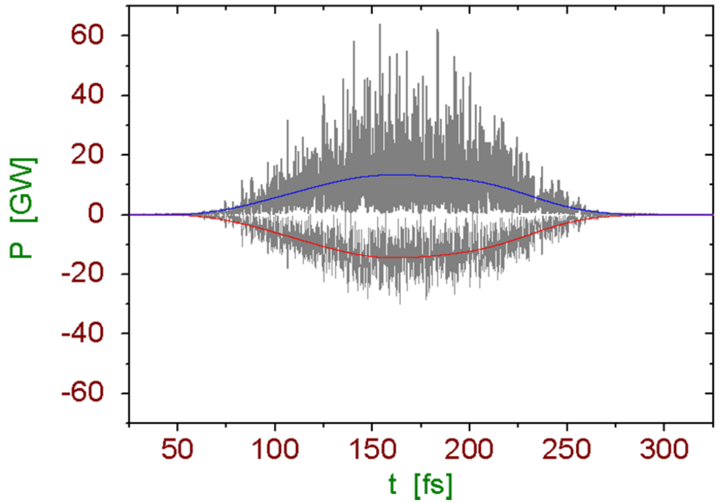
Optical afterburner for an X-ray SASE FEL

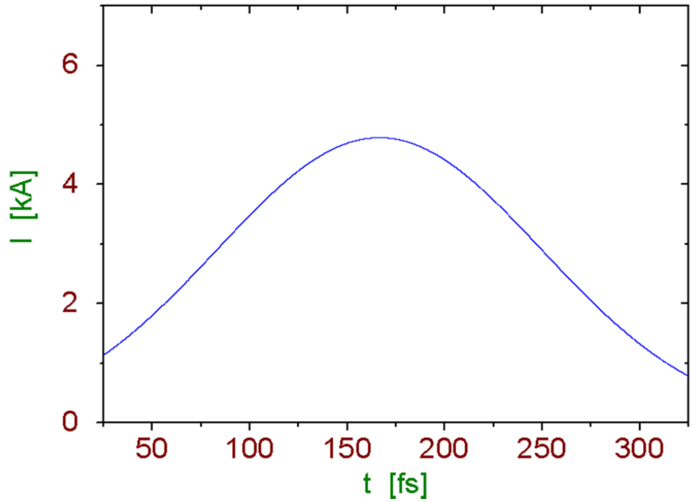


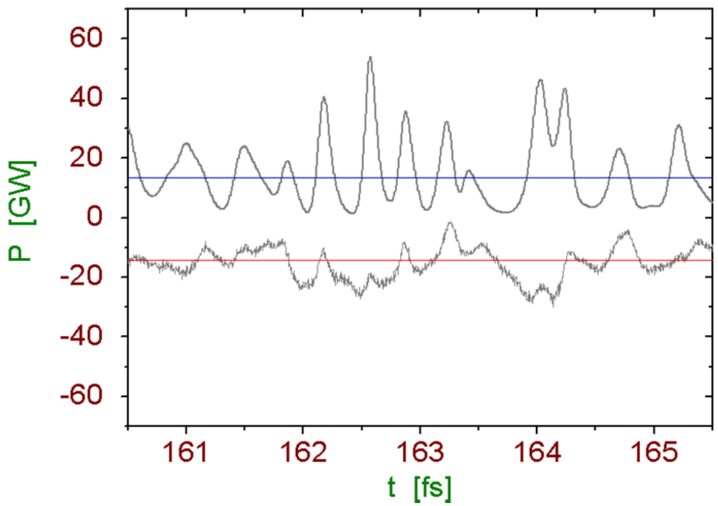
- Makes “optical replica” of X-ray pulses.
- Uses intrinsic features of SASE process.
- Very simple scheme, does not require external lasers etc.

Saldin, Schneidmiller, Yurkov, Phys. Rev. ST-AB 13, 030701 (2010)

Principle of operation

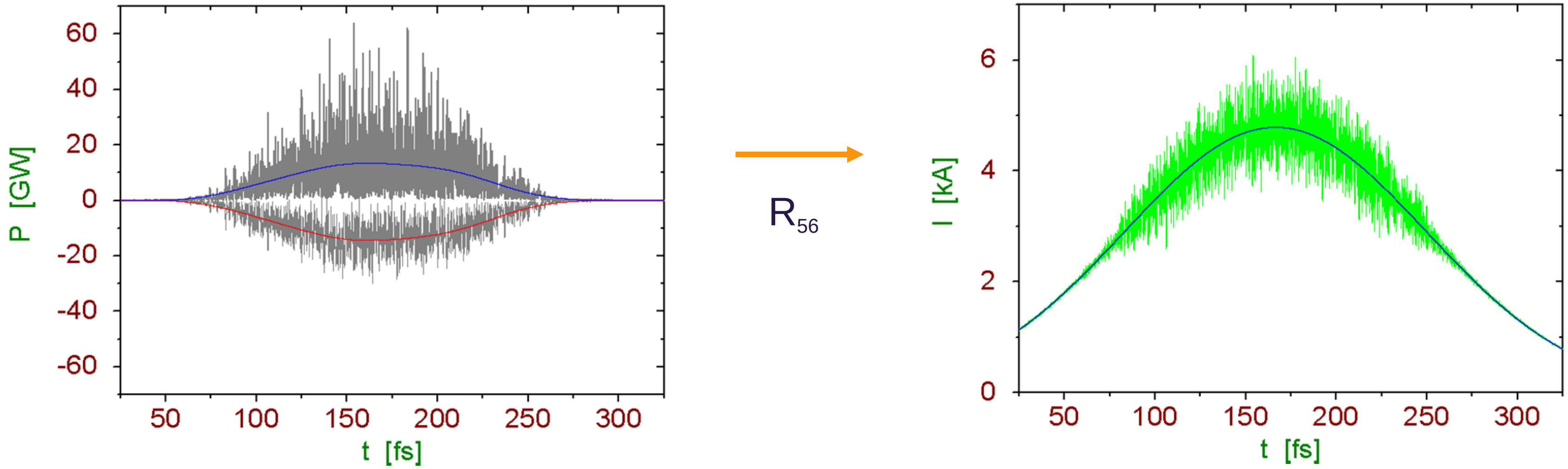






- There are density and energy modulations on the scale of FEL wavelength (Angstroem) with a chaotically changing amplitude on the scale of L_c .
- There is (practically) no density modulation on the scale $L_{c.}$
- There is mean energy loss on the same scale L_c .

Principle of operation

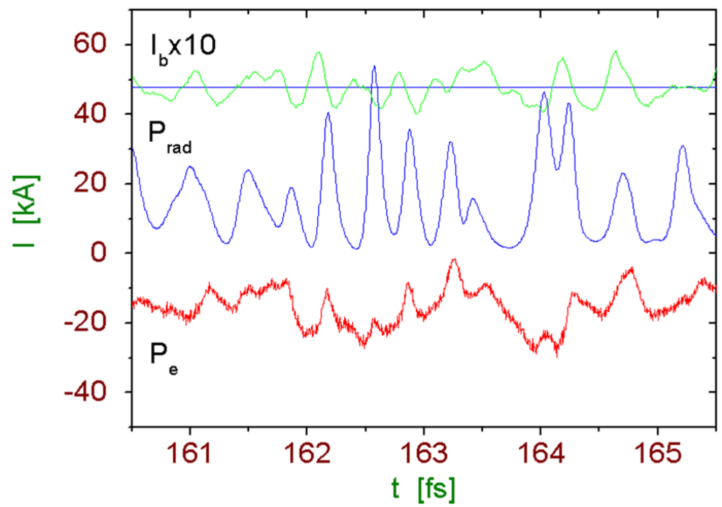


- Dispersion section converts energy modulations into the density modulations:

$$I/I_0 \simeq 1 - \hat{R}_{56} \frac{\partial < \hat{P} >}{\partial \hat{s}} + \frac{\hat{R}_{56}^2}{2} \frac{\partial^2 < \hat{P}^2 >}{\partial \hat{s}^2} + \dots$$

$$\hat{R}_{56} = \rho^2 k_r R_{56} \qquad \hat{s} = \rho k_r s$$

$$\hat{P} = P/(\rho E_0) \qquad P = E - E_0$$

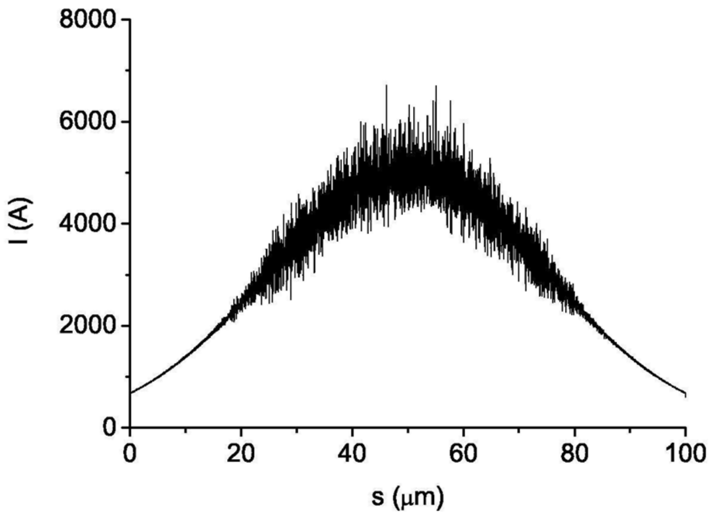


Example for SASE1

TDR-2006 case:

1 nC, ε_n = 1.4 mm-mrad

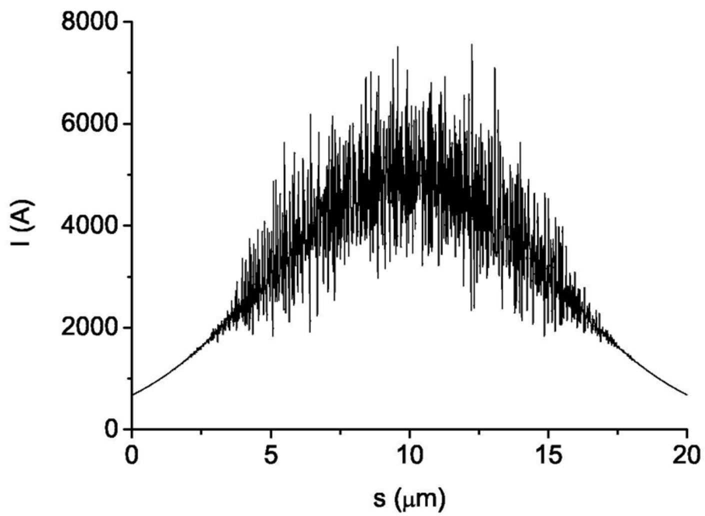
R_{56}= 50 μm



Low emittance case:

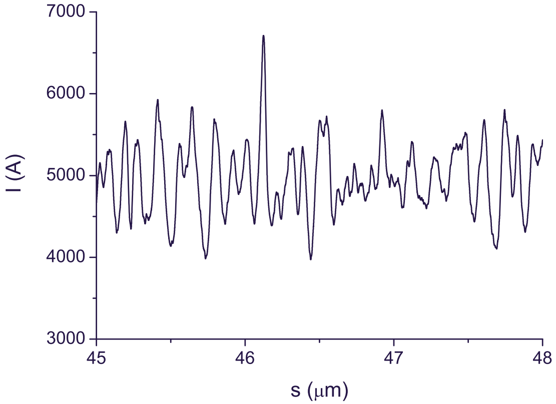
200 pC, ε_n = 0.4 mm-mrad

R_{56}= 10 μm

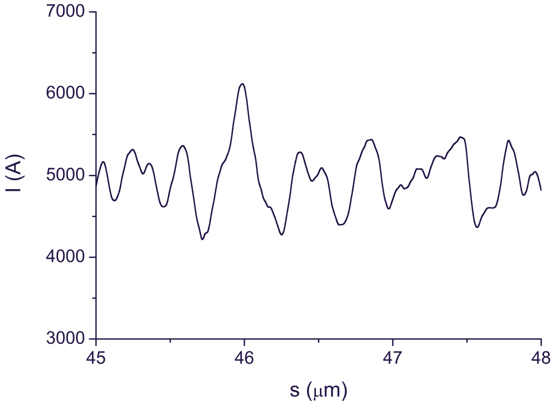


Example for SASE1: TDR-2006 case

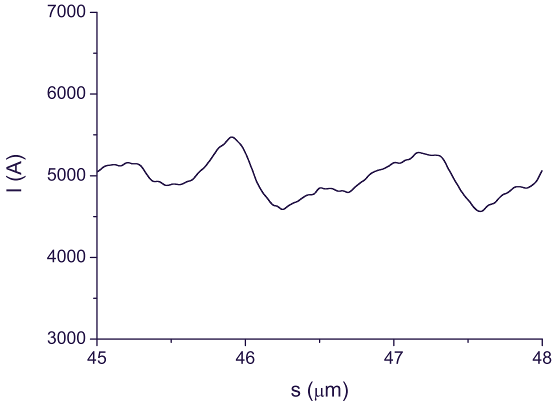
R_{56}= 50 μm



R_{56}= 200 μm



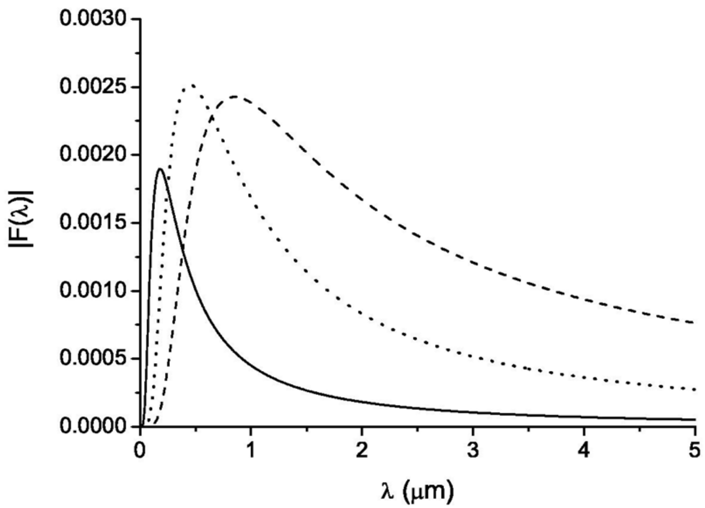
R_{56}= 500 μm

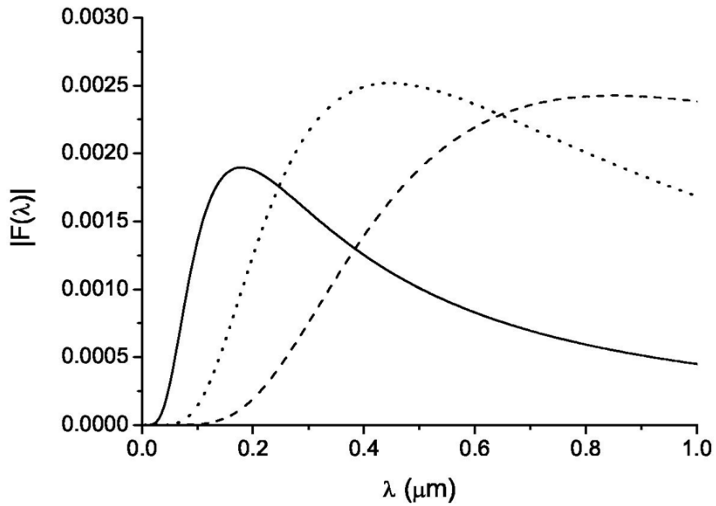


One can control modulation scale by changing R_{56}

Averaged bunch form-factor: TDR-2006 case

Solid: R_{56}= 50 µm, dot: R56= 200 µm, dash: R56= 500 µm



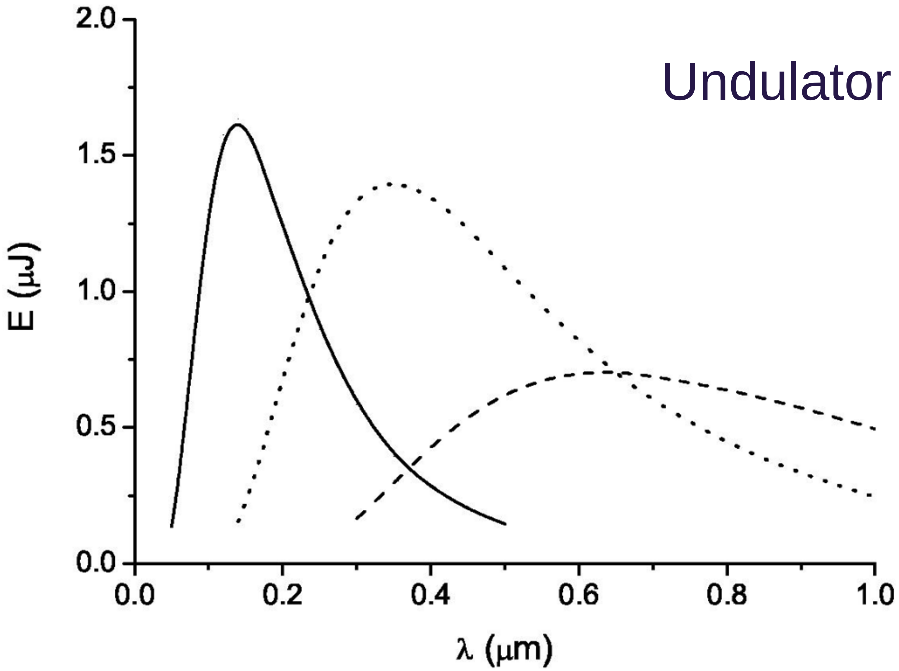


$$F(\lambda) = \int_{-\infty}^{\infty} ds f(s) e^{i2\pi s/\lambda}$$

$$P(\lambda) = p_1(\lambda)[N_e + N_e(N_e - 1)|F(\lambda)|^2]$$

Undulator radiation: TDR case

Solid: R_{56}= 50 µm, dot: R56= 200 µm, dash: R56= 500 µm



Undulator is similar to that installed at FLASH:

10 periods,
period length 70 cm,
maximum field 1.2 T

Pulse energy within coherent angle, 10% BW

European XFEL

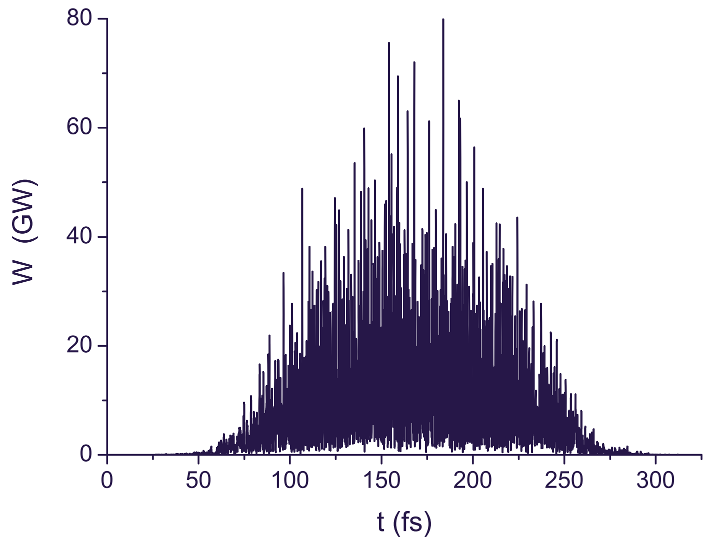
On-line monitoring of X-ray pulse duration

- “Visualization” of X-ray pulse, i.e. translating its width and shape into optical range (making “optical replica”).
- On-line measurement with FROG or similar devices.
- Radiator, transport, measurement: $\Delta\omega \gg 1/\Delta T_{sase}$
- Measure ensemble-average envelope.

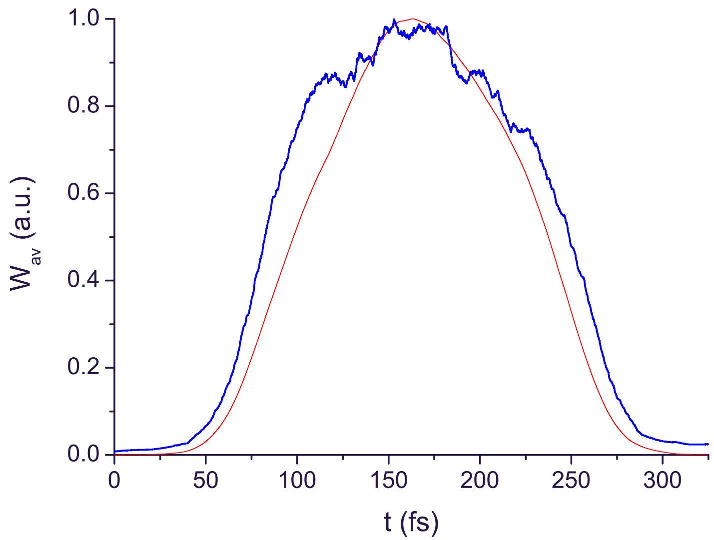
DESY HELMHOLTZ ASSOCIATION

On-line monitoring of X-ray pulse duration

Simulation of a single shot reconstruction: SASE1 at saturation:



single shot



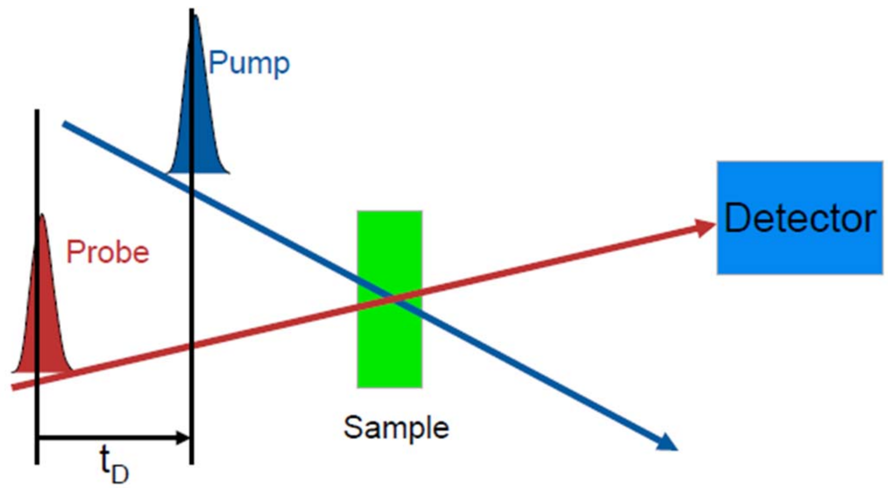
red: ensemble average FEL power

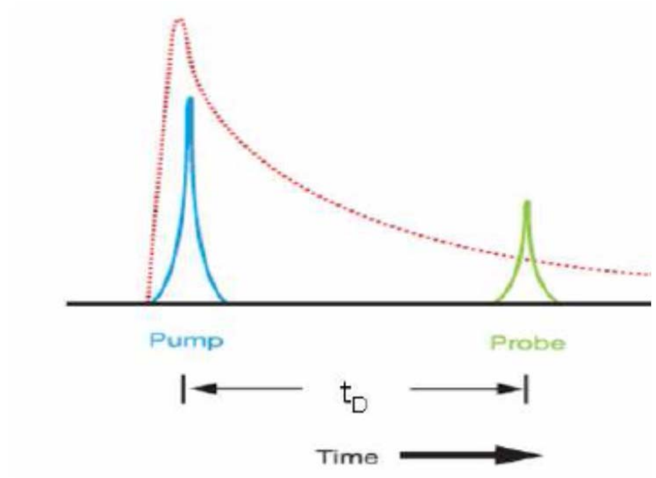
blue: reconstruction (adjacent averaging used)

Time resolution of a PP experiment

Resolution is limited by:

- Pulse duration of pump and probe pulses
- Timing jitter between the two pulses

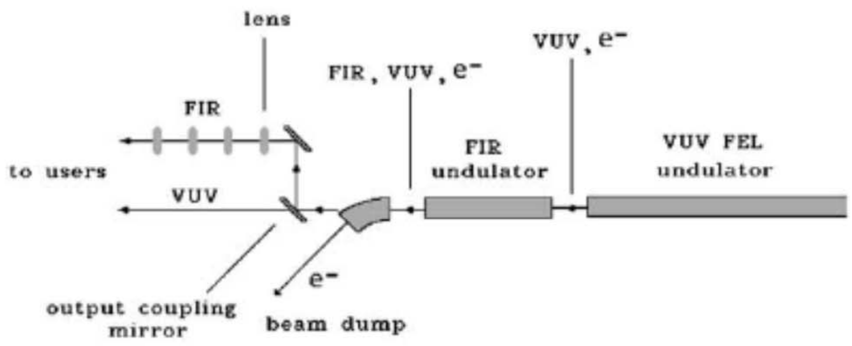




PP experiments with femtosecond resolution at XFELs?

- At FLASH 10 fs long (FWHM) soft X-ray pulses can be delivered to users.
- At LCLS low charge bunches (20 pC) are believed to produce single-digit fs pulses (hard and soft X-rays).
- However, the resolution of PP experiments at both facilities is several hundred fs due to a timing jitter.
- There are different approaches to cope with timing jitter; the most natural is to produce both pulses by the same electron bunch.

Proposal for PP experiments at FLASH (2001)



$$P(\lambda) = p_1(\lambda)[N_e + N_e(N_e - 1)|F(\lambda)|^2]$$

N·H
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 475 (2001) 363–367
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A
www.elsevier.com/locate/nima

Development of a pump-probe facility combining a far-infrared source with laser-like characteristics and a VUV free electron laser

B. Faatz[a,*], A.A. Fateev[b], J. Feldhaus[a], J. Krzywinski[c], J. Pflueger[a], J. Rossbach[a], E.L. Saldin[a], E.A. Schneidmiller[a], M.V. Yurkov[b]

[a] *DESY, Deutsches Elektronen-Synchrotron, Notkestrasse 85, D-22603 Hamburg, Germany*
[b] *Joint Institute for Nuclear Research, Dubna, 141980 Moscow Region, Russia*
[c] *Institute of Physics of the Polish Academy of Sciences, 02688 Warszawa, Poland*

- FIR undulator has been proposed by collaboration of DESY and JINR (Dubna) in 2001 (B. Faatz et al., NIMA 475(2001)363).
- FIR undulator and THz beamline have been designed, manufactured and installed at FLASH in 2007 by collaboration of DESY, Hamburg University and JINR (O. Grimm et al., NIMA 615, (2010)105, M. Gensch et al., Infrared Physics & Technology, 51 (2008) 423).

THz streak camera at FLASH

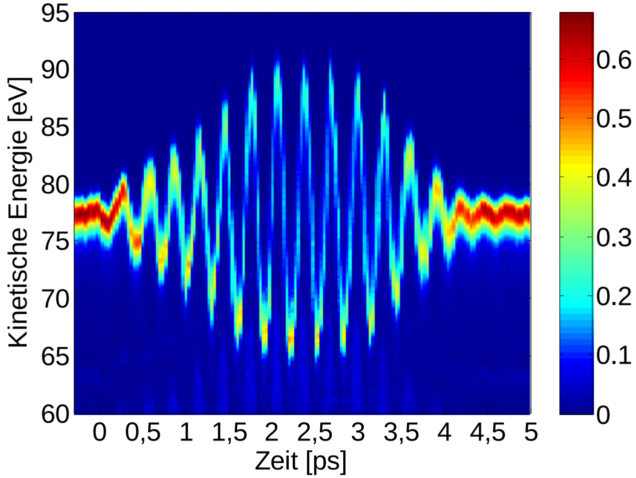
nature photonics | ARTICLES
PUBLISHED ONLINE: 23 AUGUST 2009 | DOI: 10.1038/NPHOTON.2009.160

Single-shot terahertz-field-driven X-ray streak camera

Ulrike Frühling[1], Marek Wieland[2], Michael Gensch[1,3], Thomas Gebert[2], Bernd Schütte[2], Maria Krikunova[2], Roland Kalms[2], Filip Budzyn[2], Oliver Grimm[2,4], Jörg Rossbach[2], Elke Plönjes[1] and Markus Drescher[2]*

Courtesy of Ulrike Frühling

FLASH: 13.5 nm
FIR: 85 µm
Gas: Krypton (4p)



- Two beams (FIR and soft X-ray) were transported about 100 m via separate beam lines and combined in time and space.
- Measured timing jitter was less than 5 fs rms.

Timing experiment at FLASH

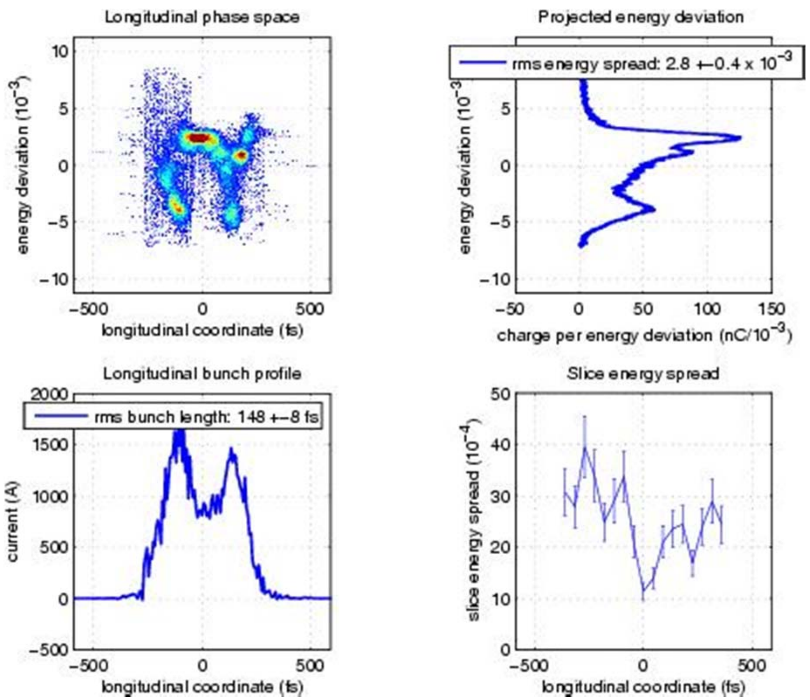
nature photonics — LETTERS
PUBLISHED ONLINE: 30 JANUARY 2011 | DOI: 10.1038/NPHOTON.2010.311

Few-femtosecond timing at fourth-generation X-ray light sources

F. Tavella[1,2]*, N. Stojanovic[1]*, G. Geloni[3] and M. Gensch[4†]*

- Coherent edge radiation (THz) is produced by a short electron bunch behind SASE undulator (FIR undulator off)
- Radiation is transported down the THz beamline and cross-corelated with high-power PP laser
- Timing accuracy 7 fs rms is achieved

Complicated electron bunches

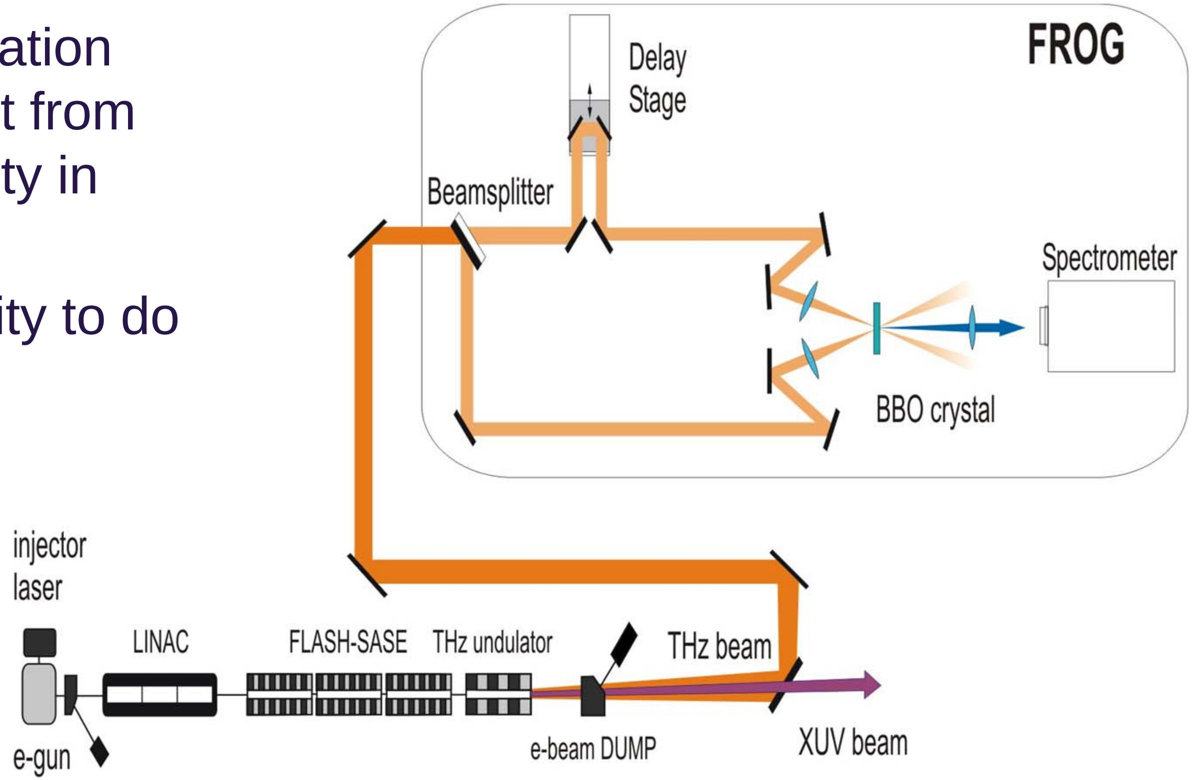


Lasing part(s): current, emittance, energy spread, mismatch, orbit etc.

Optical afterburner concept is intrinsic to SASE process:
only those parts of the bunch radiate that produce SASE.

First measurements at FLASH:
4 shifts (Nov. and Jan./Feb.), SASE at 8 and 21 nm, 100-250 uJ

- Is the coherent optical radiation coming from SASE and not from the microbunching instability in optical range?
- Do we get sufficient intensity to do FROG measurements?



This work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB.

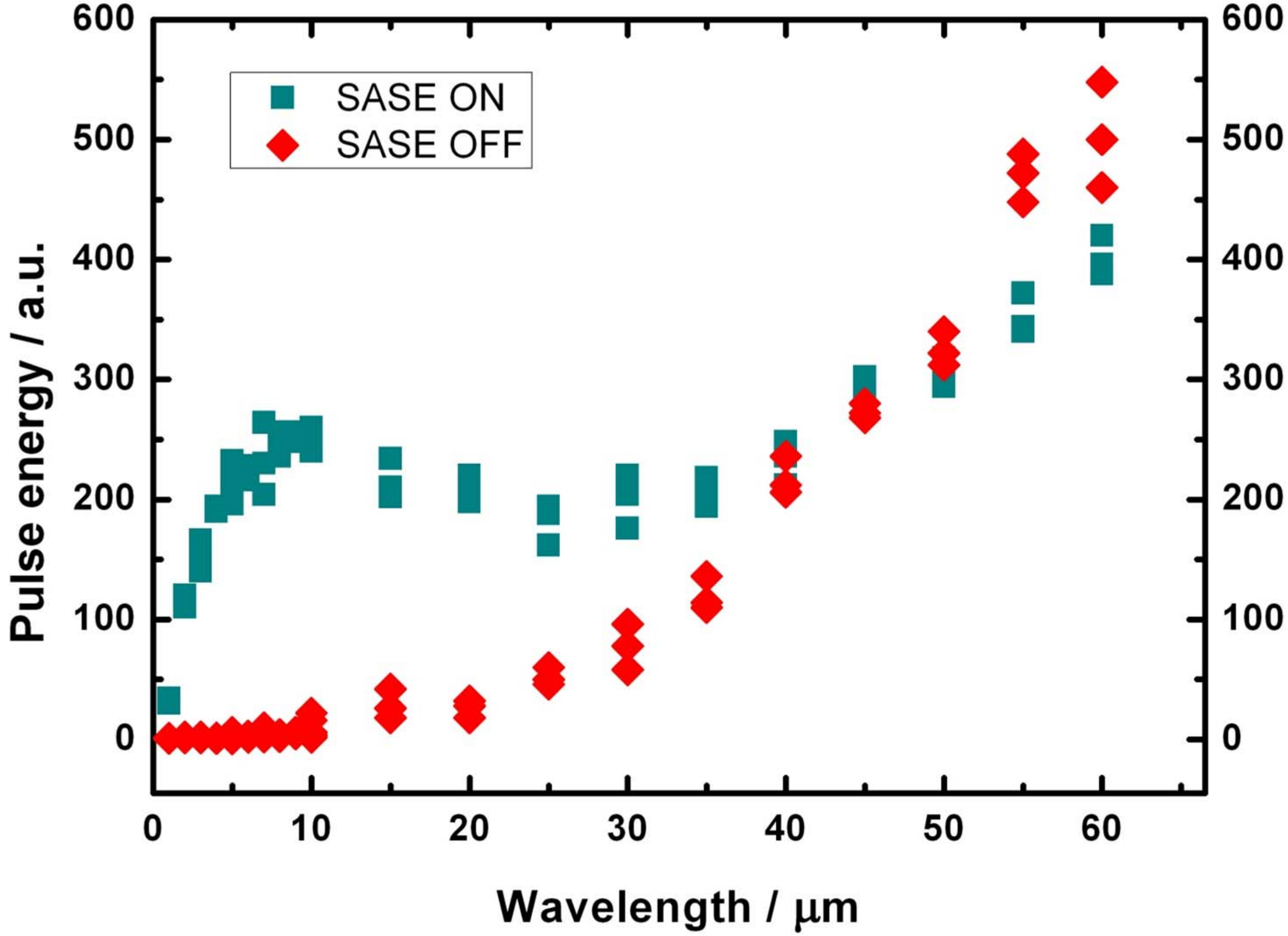
FIR undulator is used as a dispersive element. Two options for radiator:

- FIR undulator (horisontal polarization);
- select vertical polarization, use edge radiation and/or CSR from the dipole

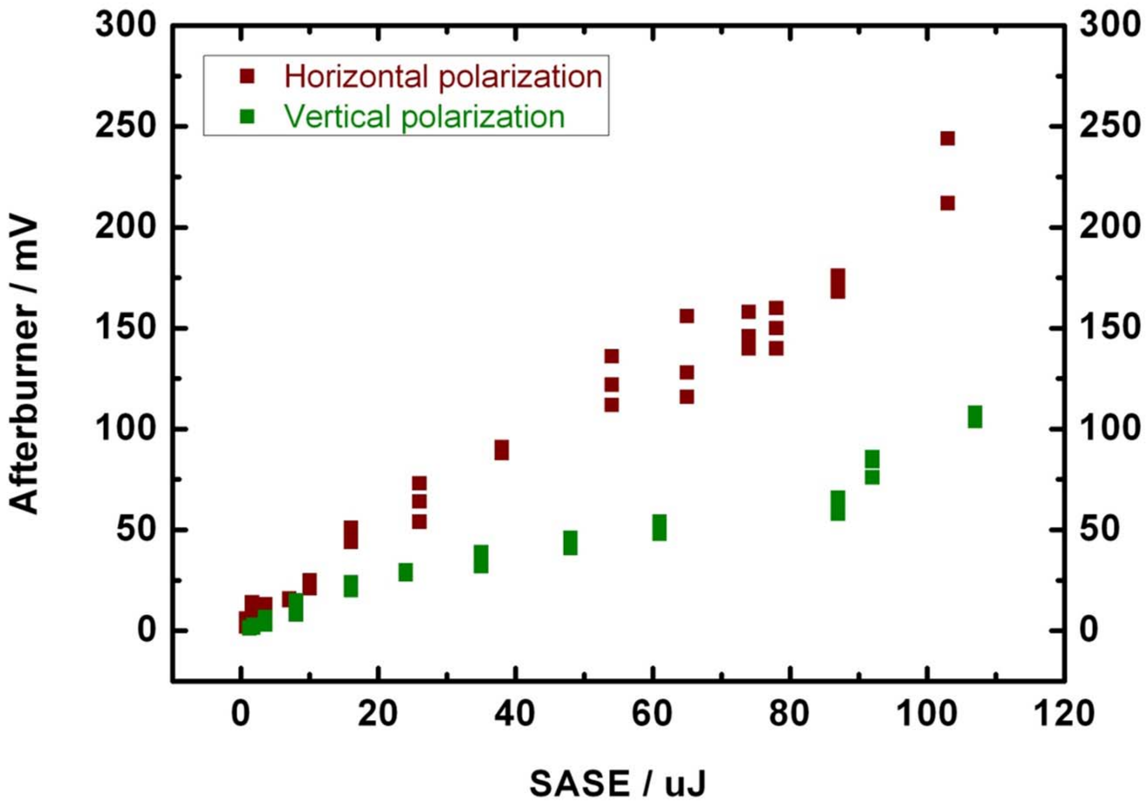
M. Gensch, E. Schneidmiller, N. Stojanovic, M. Yurkov

Photodiode (<1.1 um) versus FIR undulator tune

Horizontal polarization from the source



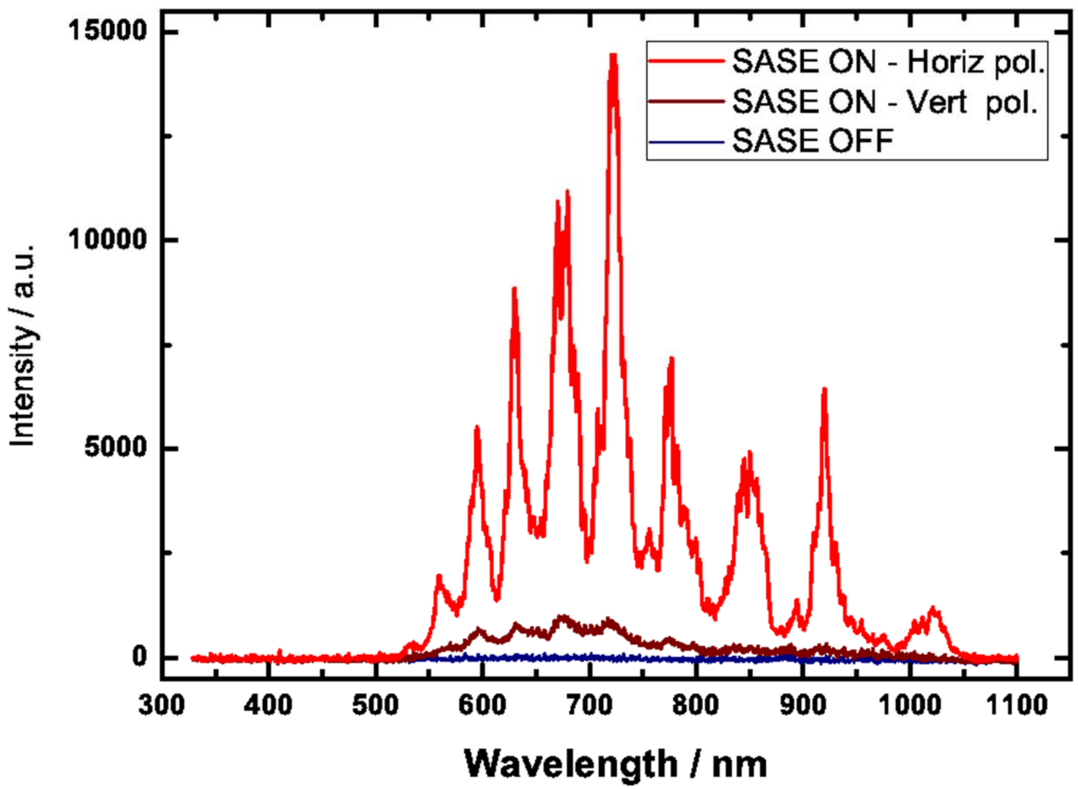
Photodiode versus SASE pulse energy



SASE at 8 nm, FIR undulator at 10 um

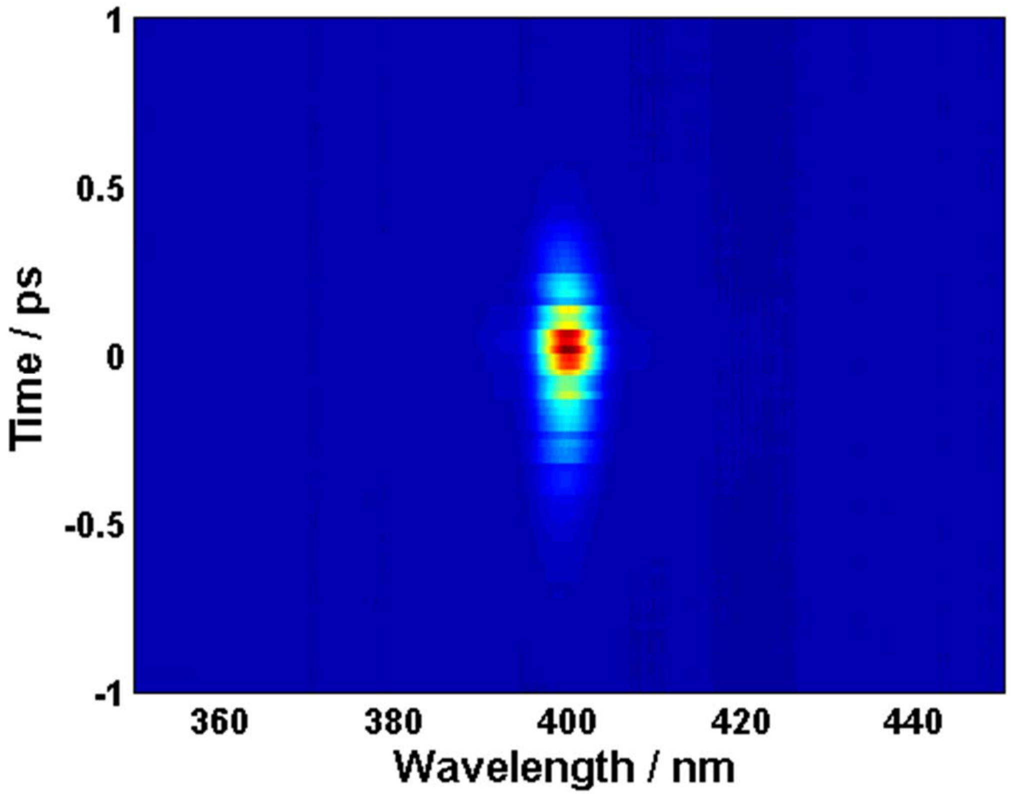
Averaged spectrum (cut from both sides)

THz undulator tuned to 10um.



SASE at 8 nm, FIR undulator at 10 um

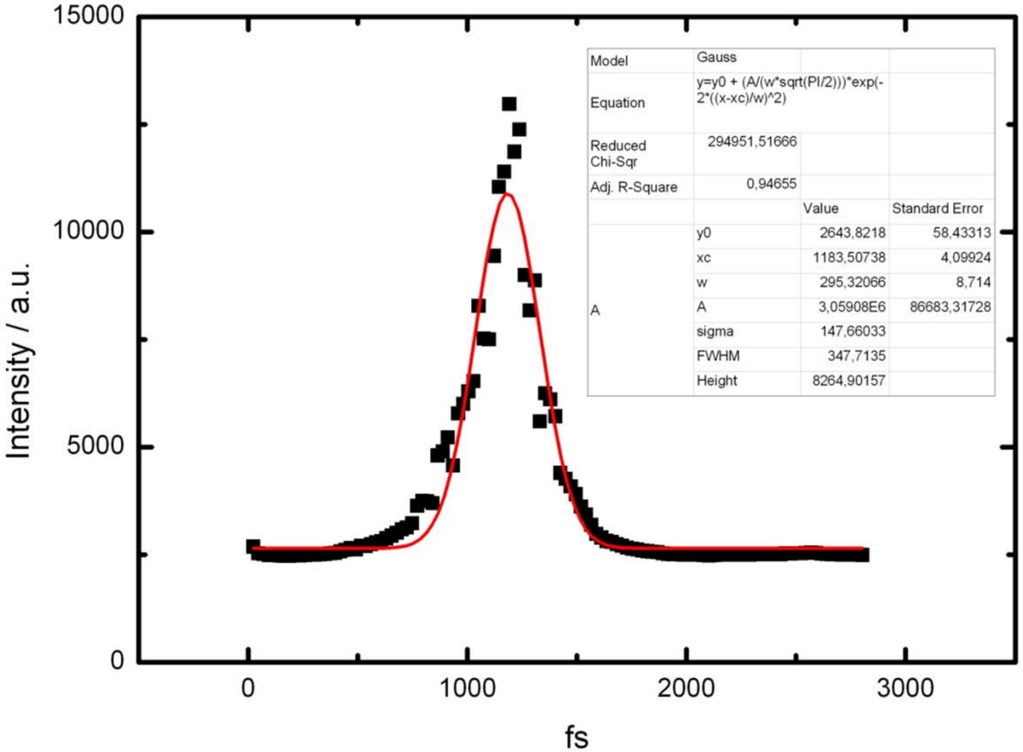
FROG trace



300 pulses for each time step (30 bunches per train, 10 Hz, 1 s)

SASE at 8 nm, FIR undulator at 800 nm

Autocorrelation



< 350 fs (FWHM);

Pulse duration should be in a range 200-300 fs (no FROG reconstruction done yet)

SASE at 8 nm (230 uJ), FIR undulator at 800 nm, charge 0.7 nC

Conclusions

- Optical afterburner concept successfully tested at FLASH: clear effect, pulse energies up to 1 uJ, first FROG traces taken.
- With some additional effort it will become a standard tool for on-line. diagnostics of SASE pulse duration and for pump-probe experiments at FLASH (on-going project).
- European XFEL (and other facilities of this kind) can profit from this scheme as well.

Acknowledgments

We would like to thank the following people for their assistance:

DESY: Franz Tavella, Tim Laarmann, Bart Faatz, Alaa Al-Shemmary, Stefan Duesterer;

CFEL/MPSD: Michael Foerst, Daniele Nicoletti, Ivanka Grguras, Adrian Cavalieri;

HZDR: Wolfgang Seidel

This work is supported by the BMBF grant nr. 05K10CHC and a collaboration of DESY, HZDR, TUB, FUB