



Examples of FLASH user experiments in 2008

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Let me apologize for many missing
transparencies which I had to take out
in order not to endanger the publishing
process of the presented data.



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X-ray sources in research



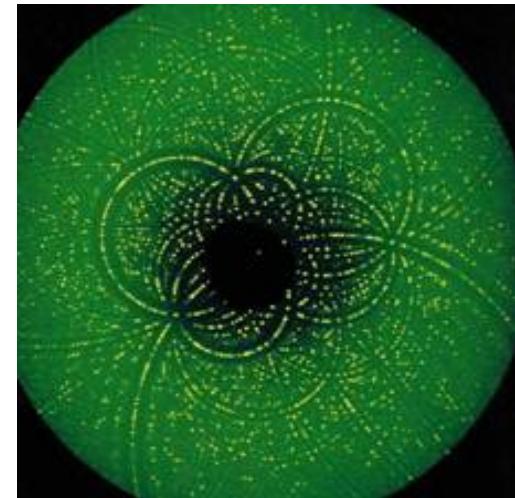
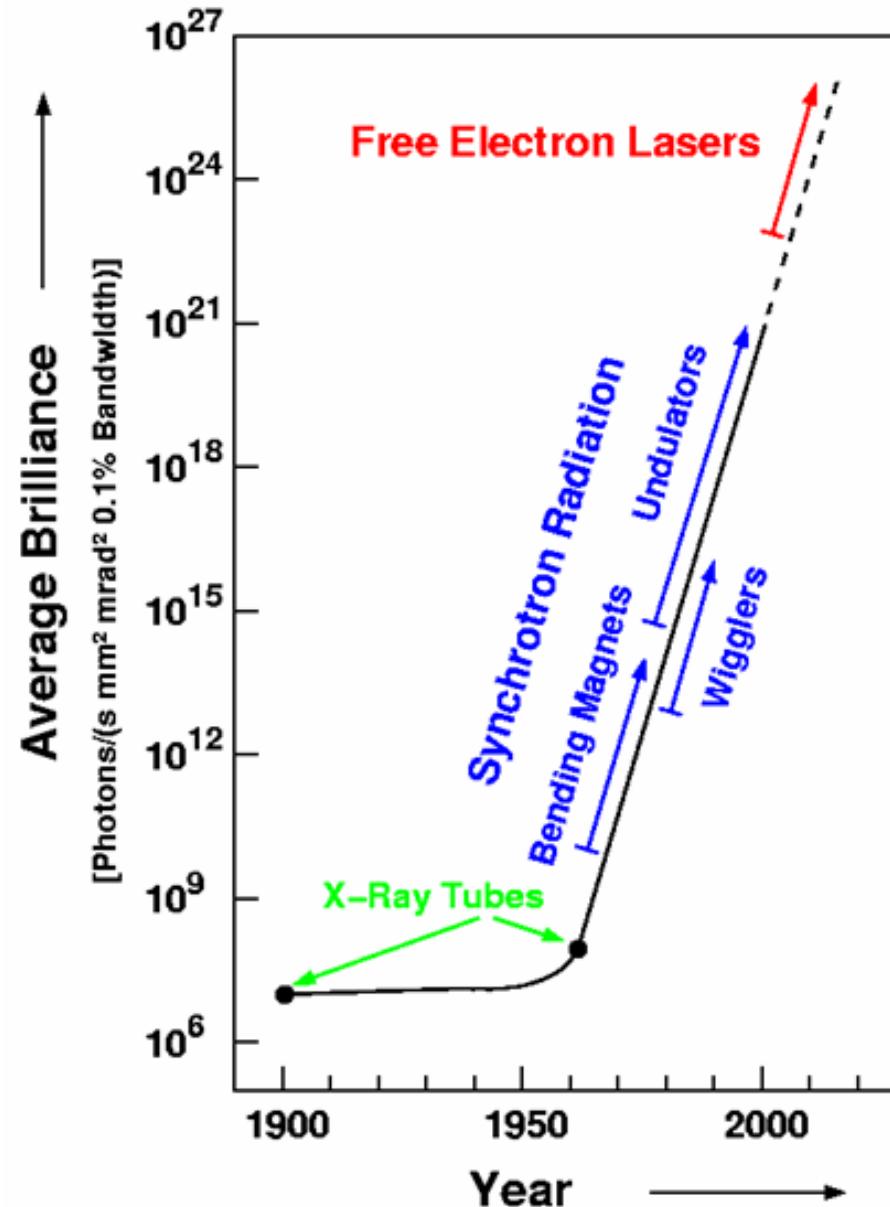
X-ray FELs

**Synchrotron Radiation
sources**

X-ray tubes

From X-ray tubes to X-ray FELs

classical
„X-ray“



crystal structure
analysis with atomic
resolution
+
information about
femtosecond
dynamics

„more light“: What is it good for?

High Intensity:

diluted samples,

e.g spectroscopy on mass selected clusters in gas phase,
highly charged ions or
single molecule diffraction

Power Density:

focused to $1\mu\text{m}^2 > 10^{16} \text{ W/cm}^2$ \Rightarrow nonlinear effects,
plasma physics

Short Pulses:

Excitation \leq timescale of molecular vibrations,

electronic relaxation, ...

\rightarrow Study of time dependent processes
(*pump and probe* - experiments)

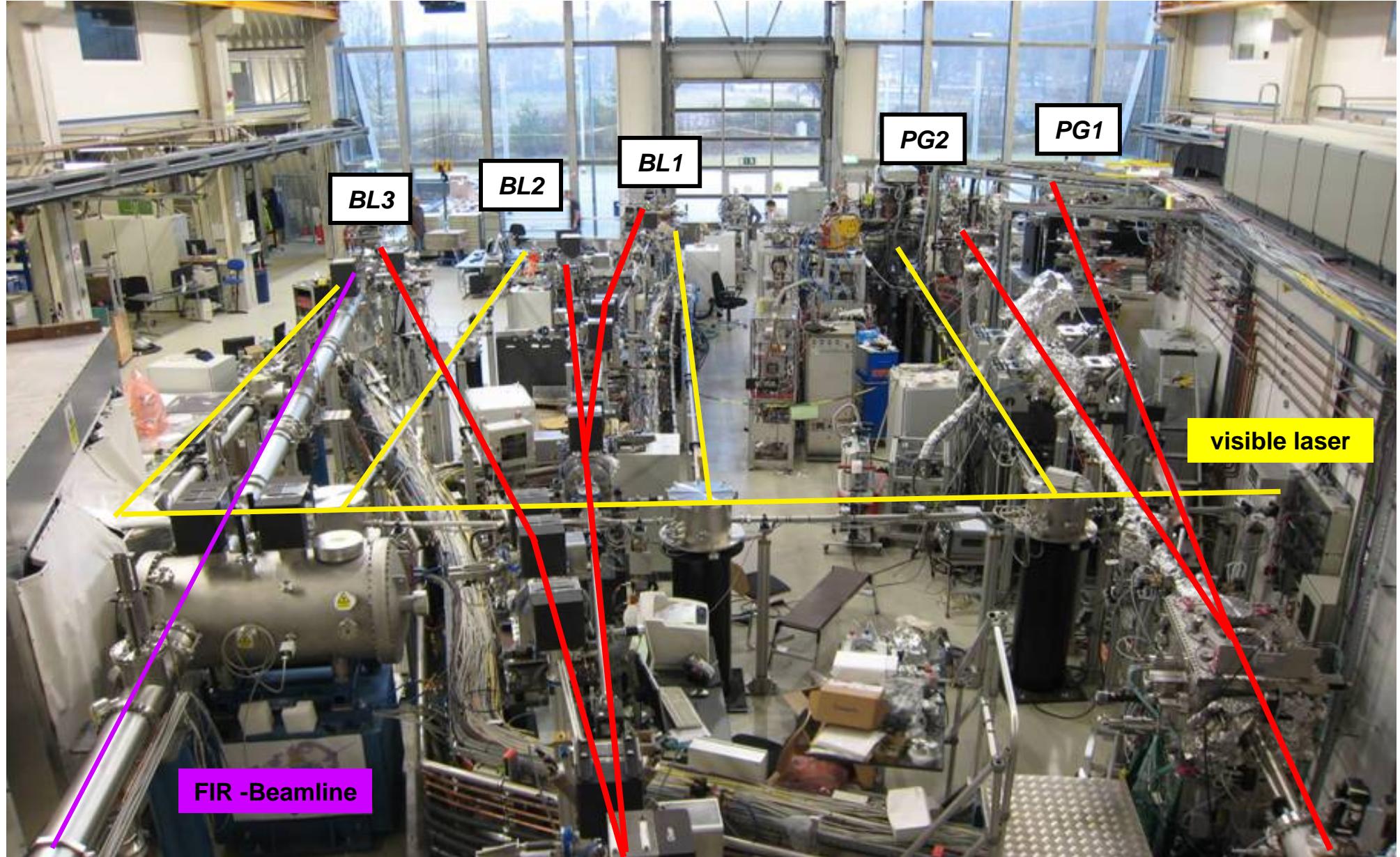
Research Highlights from FLASH



Research Areas

- **Femtosecond time-resolved experiments**
 - synchronisation FEL - optical laser
 - pump-probe experiments on atoms and molecules
 - sum-frequency generation
- **Interaction of ultra-intense XUV pulses with matter**
 - multiphoton excitation of atoms, molecules, clusters...
 - creation and characterisaton of dense plasmas
 - imaging of biological samples
- **Investigation of extremely dilute samples**
 - photodissociation of molecular ions
 - highly charged ions
 - mass selected clusters
- **Investigation of surfaces and solids**
 - XUV laser desorption
 - surface dynamics
 - luminescence under FEL radiation
 - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution

FLASH experimental hall



Research examples

- FIR – XUV pump probe / “Streak Camera” (U.Frühling et al.)
- Single shot diffraction imaging (Chapman, Hajdu et al.)
- Coherent & magnetic scattering (DESY, BESSY, Uni HD, FH Remagen)
- Pump-probe experiment on CO₂ alignment (AMOLF Amsterdam)
- Femtosecond X-ray/optical cross-correlator (FU Berlin, Uni HH, DESY)
- Soft X-ray Autocorrelators (“Split & Delay Units”) (1. Uni Münster, BESSY & 2. Uni HH)

Streaking with FIR light

U. Frühling et al. (PhD thesis)

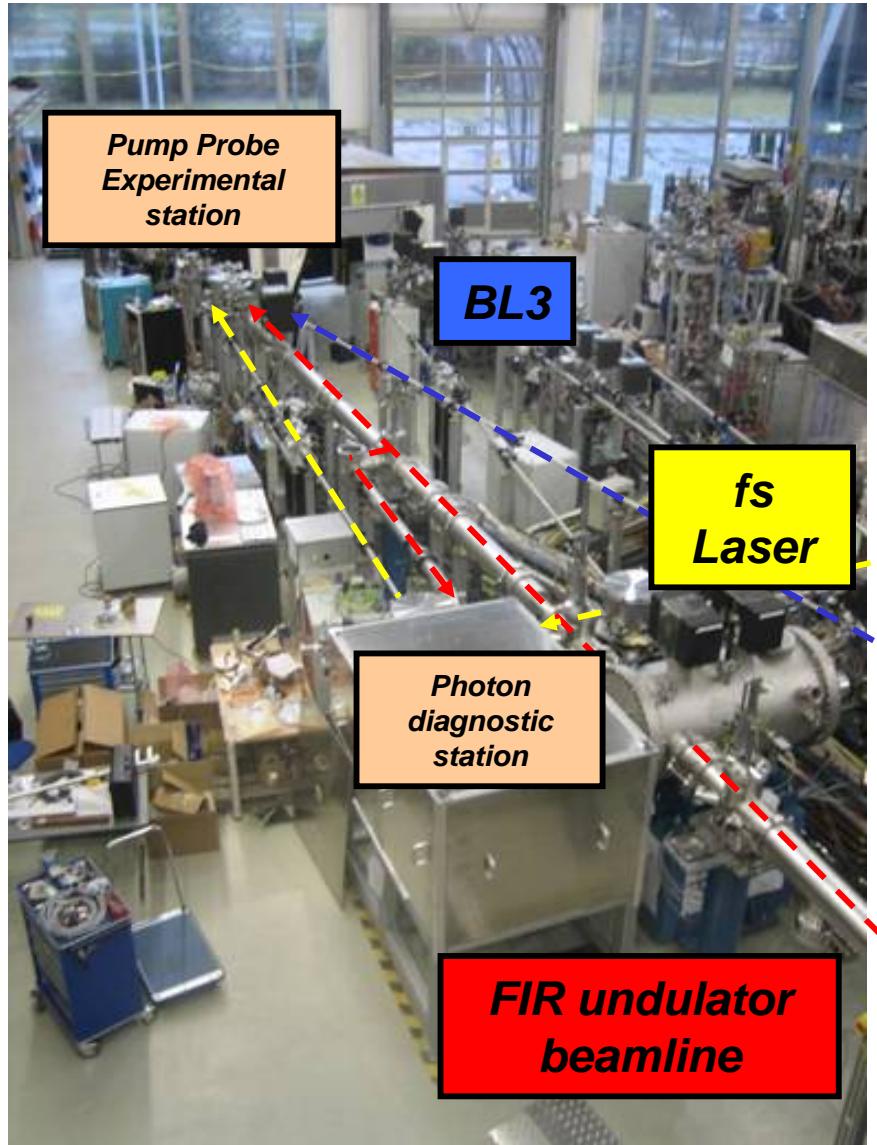


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→ Ulrikes talk in FLASH seminar Feb. 2008

Coherent single-shot X-ray diffraction imaging

H. Chapman, J. Hajdu et al.

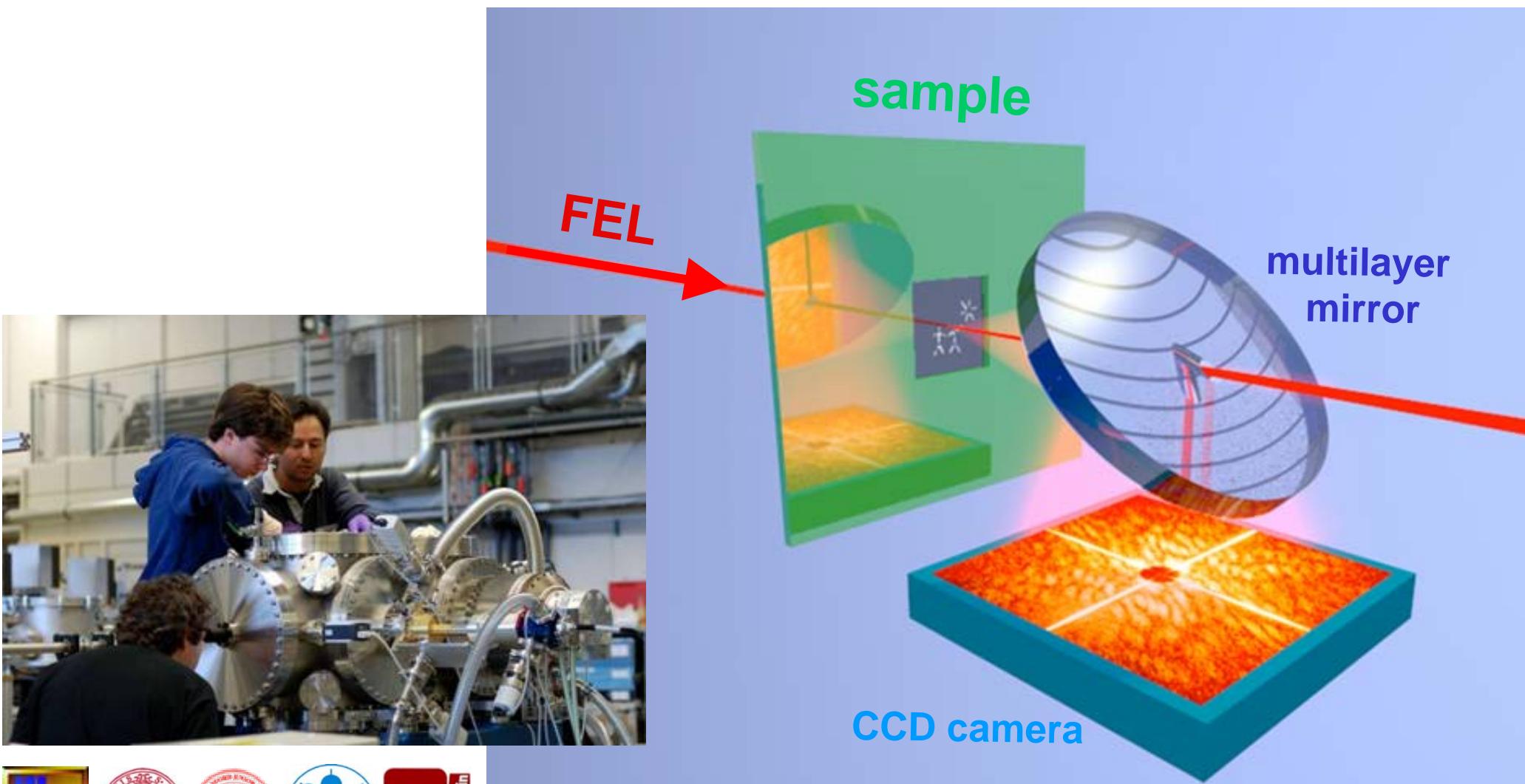
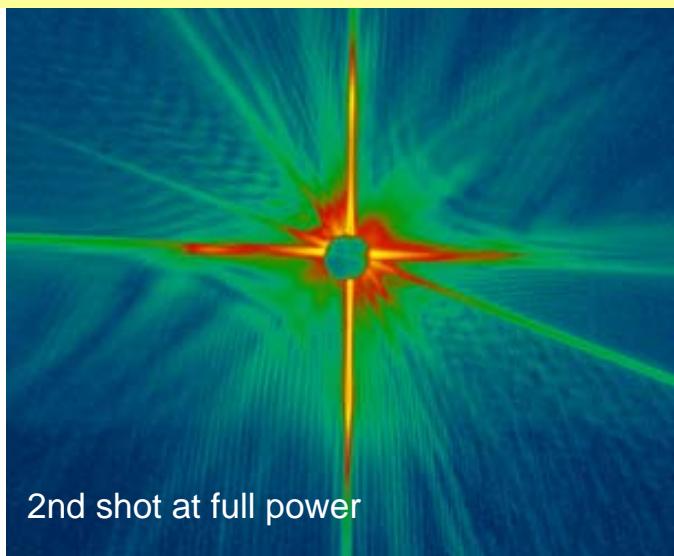
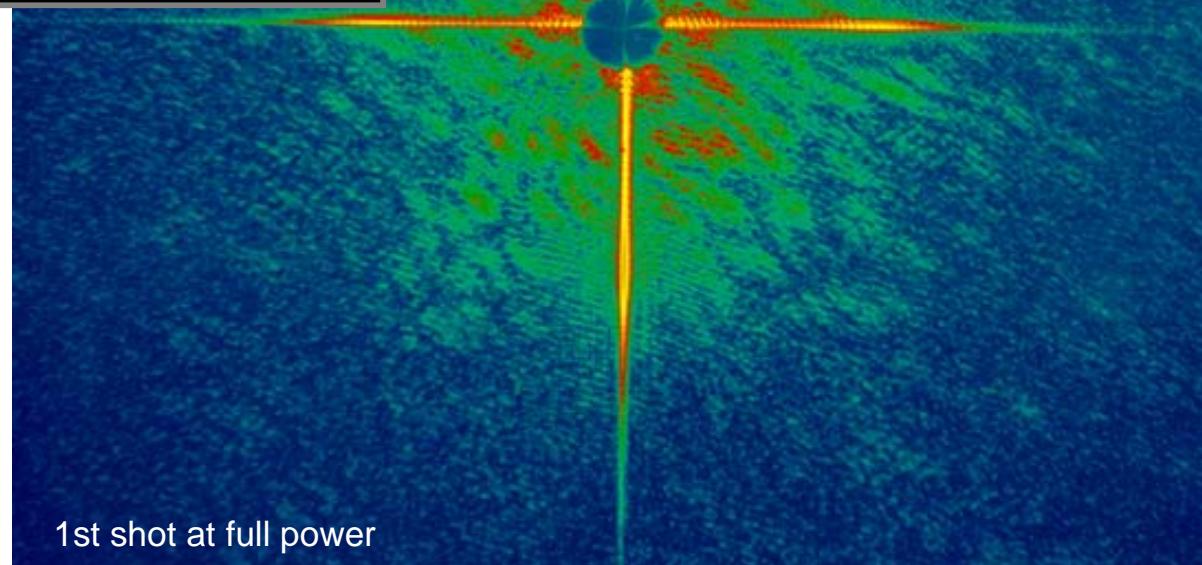


Image reconstructed from ultrafast diffraction pattern

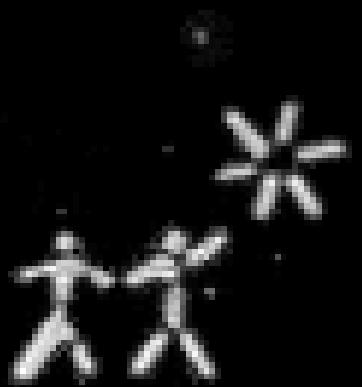
1 micron



SEM of structure milled into silicon nitride membrane



Reconstructed Image – achieved diffraction limited resolution!
Wavelength = 32 nm



LETTERS

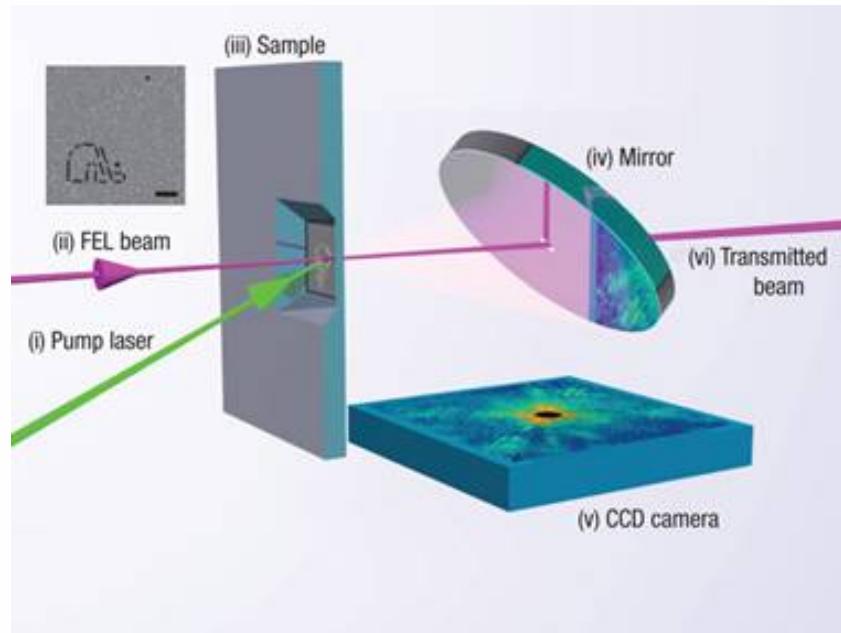
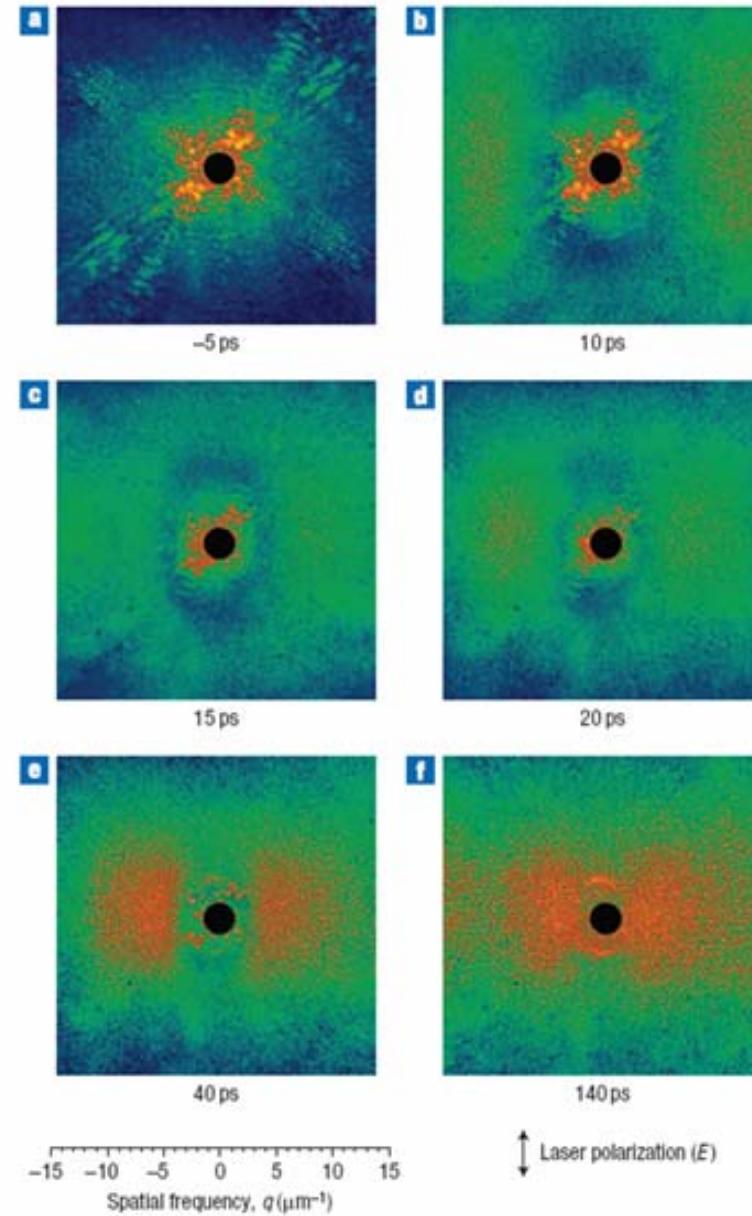
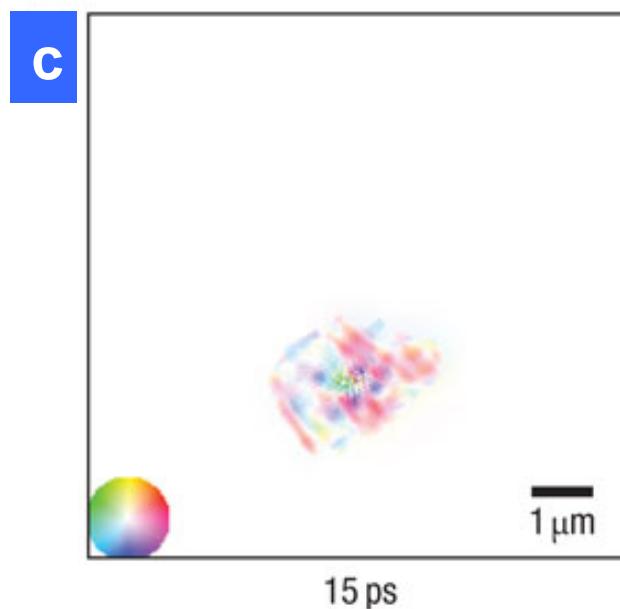
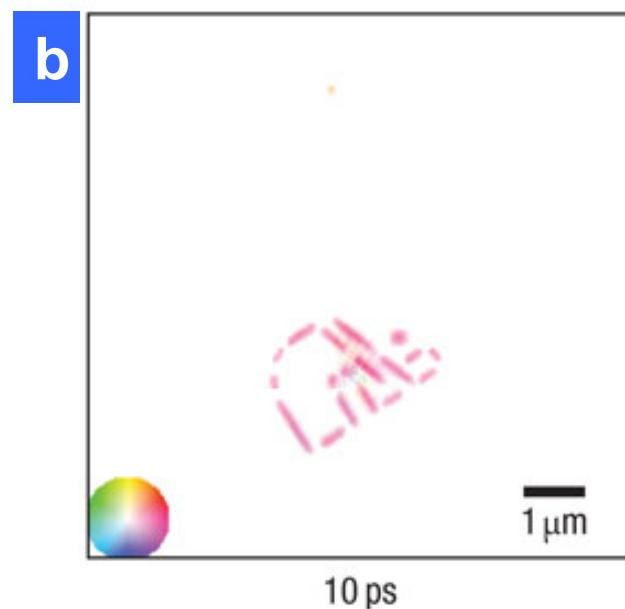
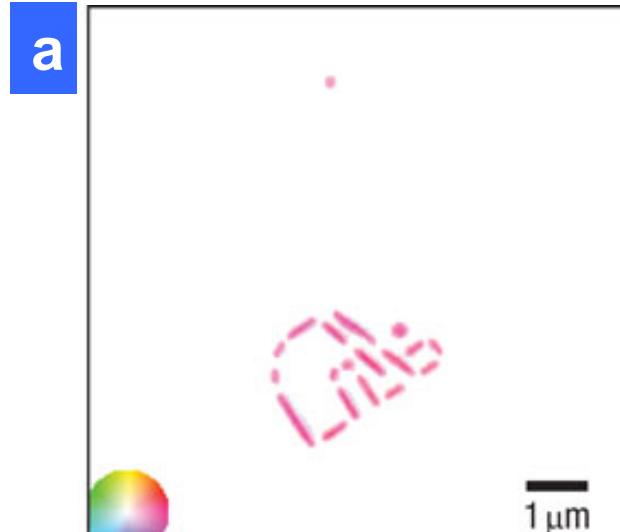
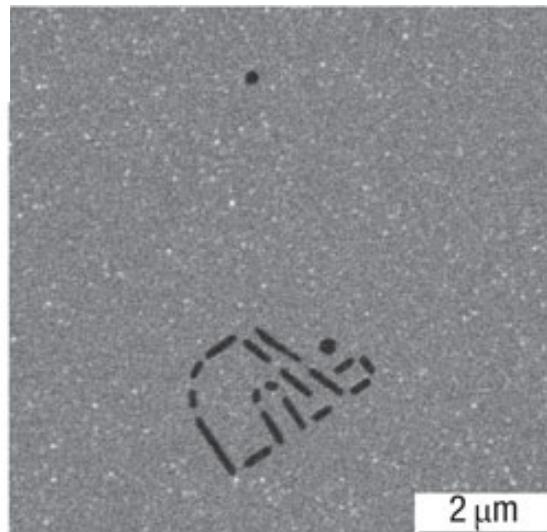


Figure 1 X-ray dynamic diffraction imaging. A visible-light laser beam (i) incident from the left is focused onto the sample (iii) and acts as the excitation pulse. A 10-fs duration soft X-ray pulse at a wavelength of 13.5 nm from the FEL (ii) is focused to a 20- μm spot in the same location as the visible-light laser at a continuously variable delay after the excitation pulse. The X-ray pulse diffracts from the sample, carrying information about the transient sample structure to the CCD detector (v) in the form of a coherent diffraction pattern. A 45° mirror (iv) is used to separate the direct beam from the diffracted light: the direct FEL beam (vi) passes straight through a hole in the mirror and is not detected in the CCD image. A 100-nm-thick zirconium filter over the CCD chip makes the detector blind to the laser excitation pulse. The sample (iii) consisted of a nanometre-resolution pattern etched into a silicon nitride membrane using a focused ion beam (FIB), providing a well-defined control sample so that the time evolution of a known structure could be observed. The path length from sample to CCD is 53 mm and the detected numerical aperture is 0.25, giving a spatial resolution of 27 nm in the sample plane.



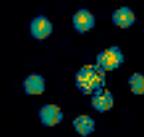


True “high speed recording” of an explosion

Single-shot diffraction image of Al structures 20 ps after heating at 13.5 nm

A. Barty et al.,
FLASH Logbook,
10. Nov. 2008

Reconstruction

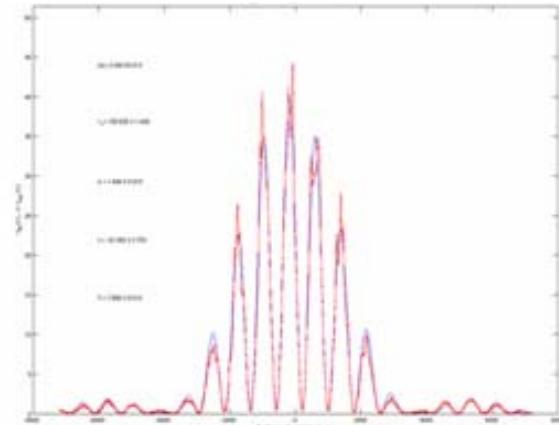
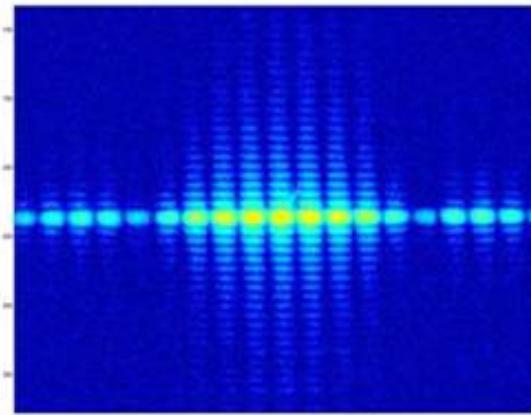


A diffraction pattern and its real-space reconstruction, which was done at the beamline whilst collecting data. The sample is a pattern of Al cylinders, fabricated by e-beam lithography. The image was captured 20 ps after being hit by the FEL pulse (we used a multilayer mirror in the time-delay geometry to probe the sample with the same pulse that initiated the explosion). We will analyse the time series from identical structures to watch the evolution of the FEL-induced explosion.

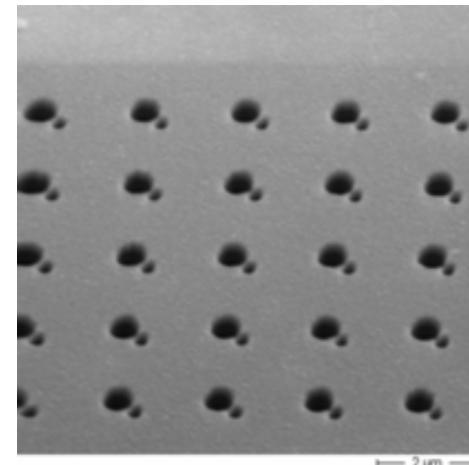
Coherent scattering experiment

DESY, BESSY, Univ. Heidelberg, Rhein-Ahr-Campus Remagen

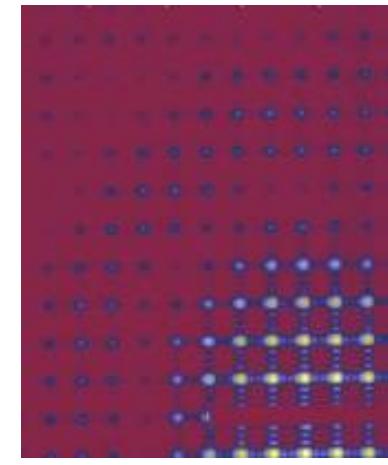
CxDI measurements at fundamental: 8 nm



Sample: double slit 5 μm separation



Exp. data and theor. Fit \rightarrow 98% coherence



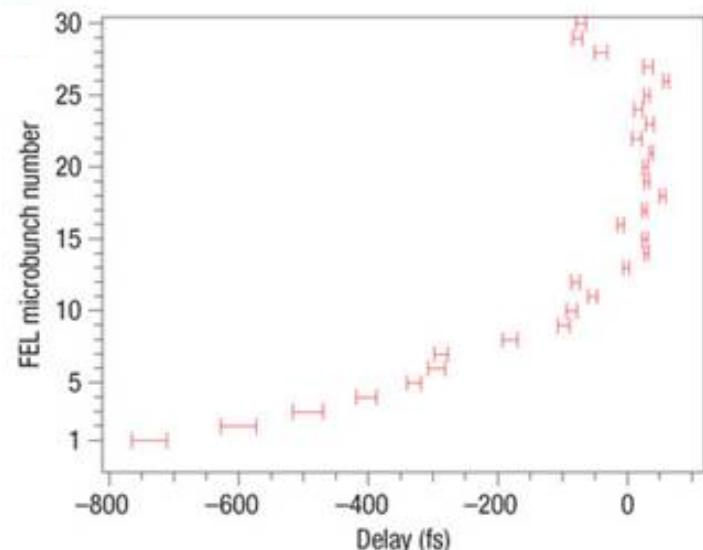
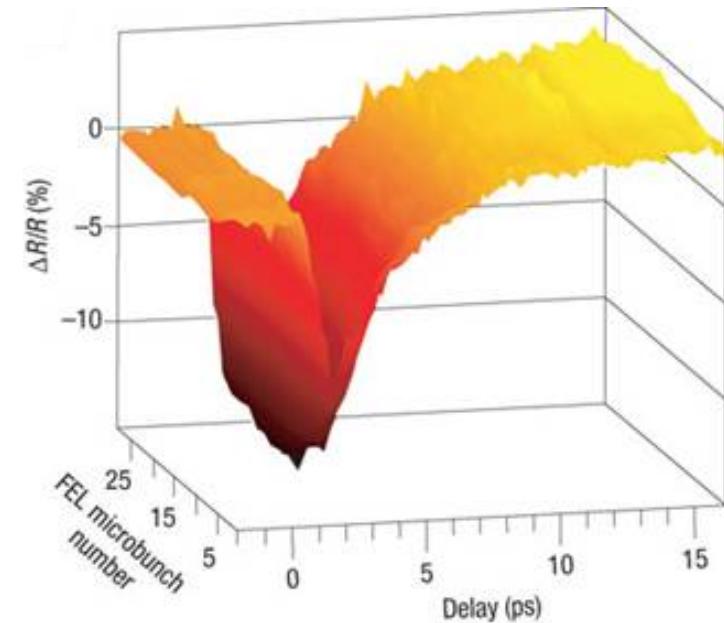
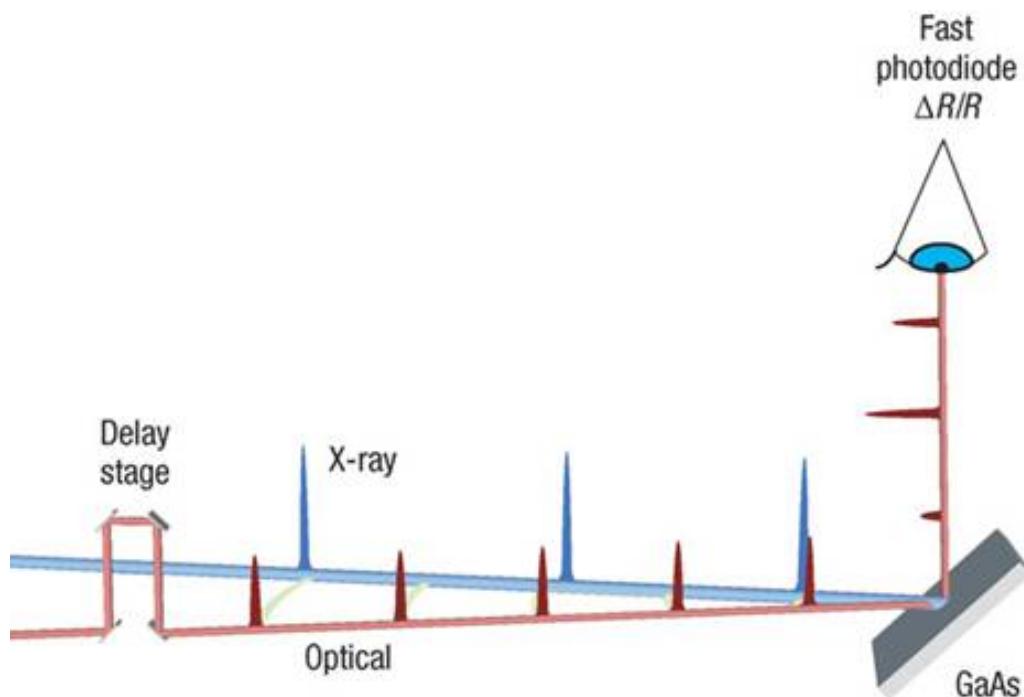
Sample: prepared by FIB

Experimental Diffraction Pattern

Femtosecond X-ray/optical cross-correlator

FU Berlin, Uni HH, DESY

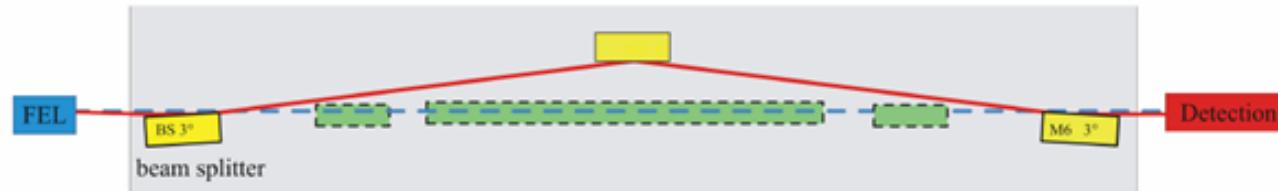
- use GaAs crystal
- change optical properties with FEL pulse
- probe with optical laser via changes in reflectivity



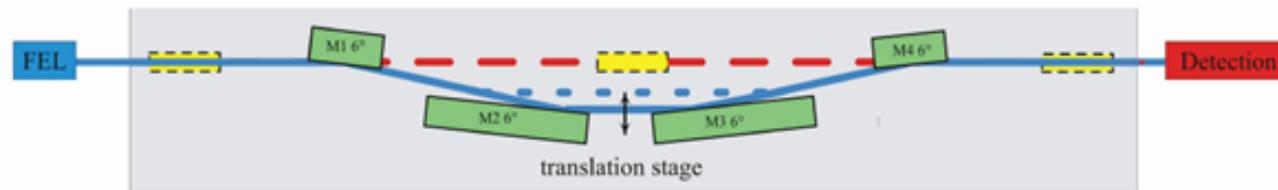
Autocorrelator / beam splitter (1)

Uni Münster (H. Zacharias), BESSY, DESY

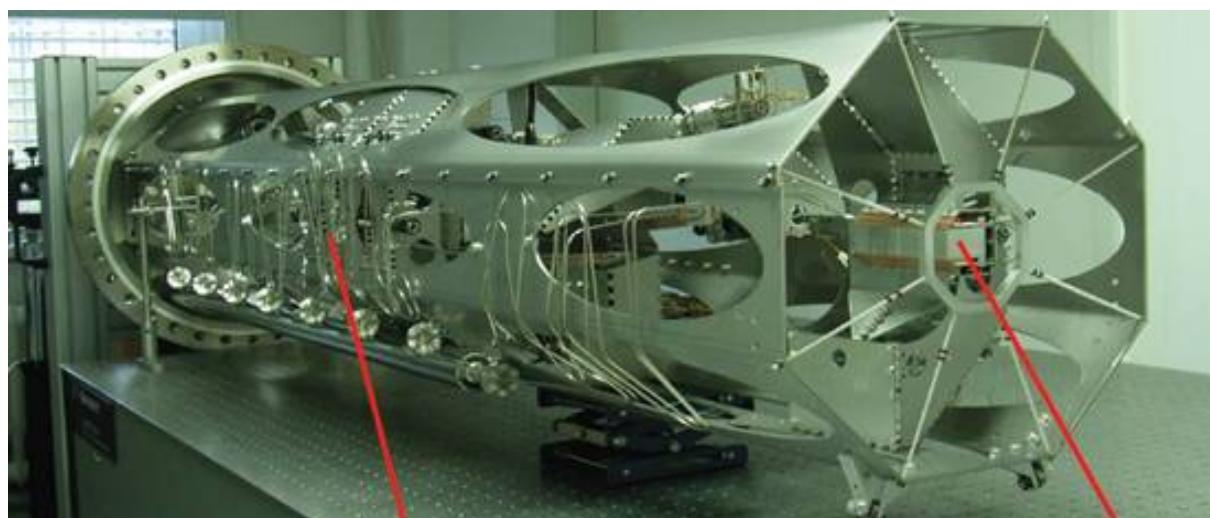
top view - fixed delay arm



side view - variable delay arm



150 cm





Longitudinal coherence of FLASH pulses (1)

Figures omitted here

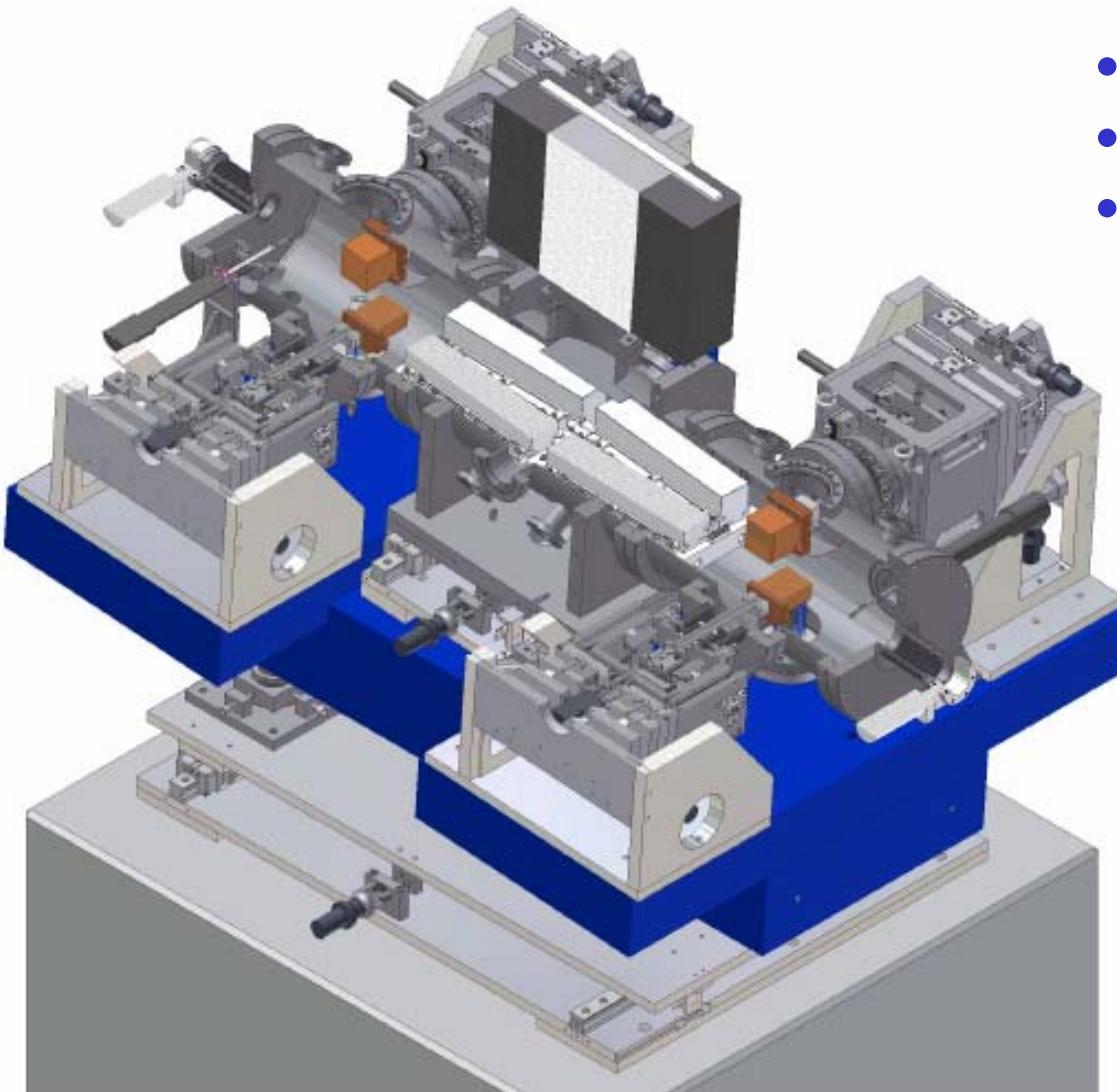
Coherence length at 8 nm:~10 fs (~7 fs for 3rd harm.)

Pulse duration at 24 nm: ~30 fs

Uni Münster (H. Zacharias), BESSY, DESY

Autocorrelator / beam splitter (2)

Uni Hamburg (A.Föhlisch, W.Wurth et al.)



- Delay Range: ± 6 ps
- Time resolution: < 1 fs
- Permanently installed in PG2



Publications (1)

48 scientific publications since 2006

10 Phys. Rev. Lett.
5 Phys. Rev. A,E
5 Appl. Phys. Lett.
1 Nature
1 Nature Physics
4 Nature Photonics
2 J. Phys. B
3 Optics Express

In addition, more than 16 submitted (6 to PRL)



Publications (2)

1. J. Chalupský, L. Juha, V. Hájková, J. Cihelka, L. Vyšín, J. Gautier, J. Hajdu, S.P. Hau-Riege, M. Jurek, J. Krzywinski, R.A. London, E. Papalazarou, J.B. Pelka, G. Rey, S. Sebban, R. Sobierajski, N. Stojanovic, K. Tiedtke, S. Toleikis, T. Tschentscher, C. Valentin, H. Wabnitz, P. Zeitoun,
Non-thermal desorption/ablation of molecular solids induced by ultra-short soft x-ray pulses,
Optics Express 17 208-217 (2009); <http://dx.doi.org/10.1364/OE.17.000208>
2. U. Zastrau, C. Fortmann, R.R. Fäustlin, L.F. Cao, T. Döppner, S. Düsterer, S.H. Glenzer, G. Gregori, T. Laarmann, H.J. Lee, A. Przystawik, P. Radcliffe, H. Reinholtz, G. Röpke, R. Thiele, J. Tiggesbäumer, N.X. Truong, S. Toleikis, I. Uschmann, A. Wierling, T. Tschentscher, E. Förster, R. Redmer,
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Phys. Rev. E 78, 066406 (2008); <http://dx.doi.org/10.1103/PhysRevE.78.066406>
3. R. Mitzner, B. Siemer, M. Neeb, T. Noll, F. Siewert, S. Roling, M. Rutkowski, A.A. Sorokin, M. Richter, P. Juranic, K. Tiedtke, J. Feldhaus, W. Eberhardt and H. Zacharias,
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Polarization Control in Two-Color Above-Threshold Ionization of Atomic Helium,
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5. S. Vielhauer, V. Babin, M. De Grazia, E. Feldbach, M. Kirm, V. Nagirnyi and A. Vasil'ev,
Self-quenching effects of excitons in CaWO₄ under high density XUV FEL excitation,
Phys. Sol. State 50, 1789-1794 (2008); <http://dx.doi.org/10.1134/S1063783408090394>
6. P. Johnsson, W. Siu, A. Gijsbertsen, J. Verhoeven, A. S.Meijer, W. van der Zande, M. J. J. Vrakking,
Velocity map imaging of atomic and molecular processes at the free electron laser in Hamburg (FLASH),
J. Mod. Optics 55, 2693-2709 (2008); <http://dx.doi.org/10.1080/09500340802393062>
7. Sébastien Boutet, Michael J. Bogan, Anton Party, Matthias Frank, W. Henry Benner, Stefano Marchesini, M. Marvin Seibert, Janos Hajdua, Henry N.Chapman,
Ultrafast soft X-ray scattering and reference-enhanced diffractive imaging of weakly-scattering nanoparticles,
J. Electron Spectrosc. Relat. Phenom. 166-167, 65-73 (2008); <http://dx.doi.org/10.1016/j.elspec.2008.06.004>

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