Parallel fs X-Ray Spectrometer

A. Erko, A. Firsov, K. Holldack

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
Elektronenspeicherring BESSY II, Albert-Einstein-Str. 15, 12489 Berlin

Motivation

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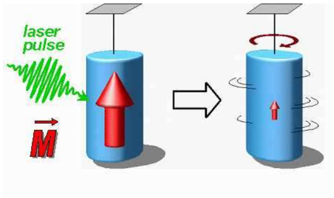
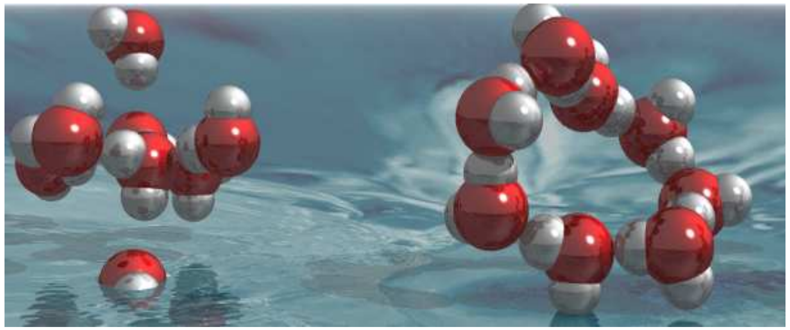
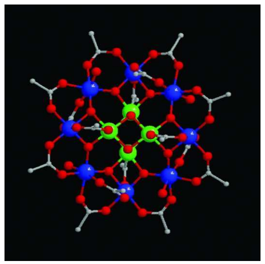


Ultrafast transfer of angular momentum between spins and lattice in ferromagnetic materials



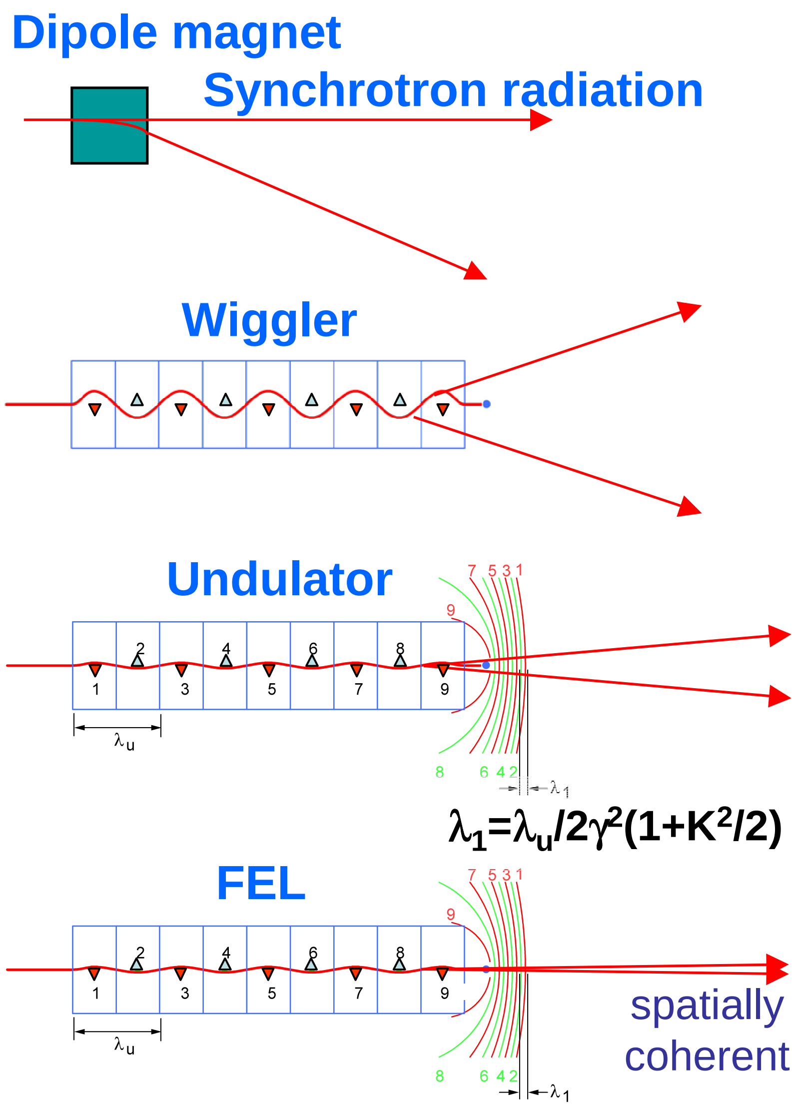
<u>Femtochemistry:</u>
Understanding the dynamics and formation of a chemical bond by time resolved electron spectro-scopy, at surfaces, in molecules, and clusters

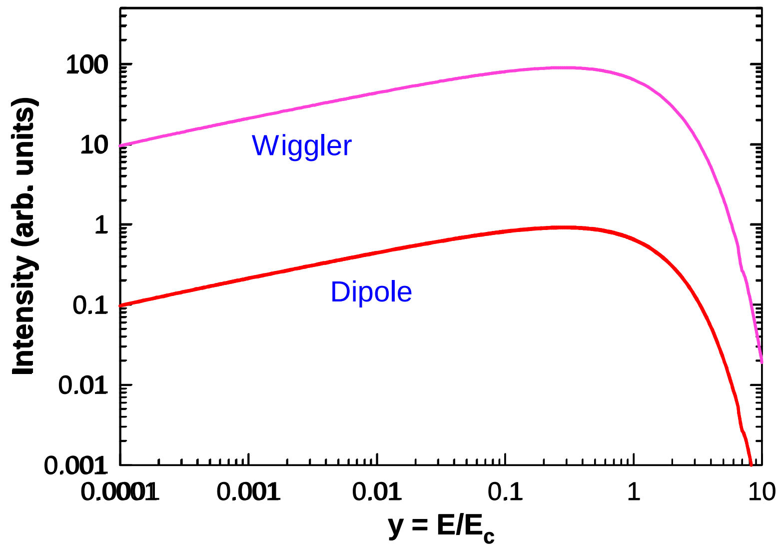


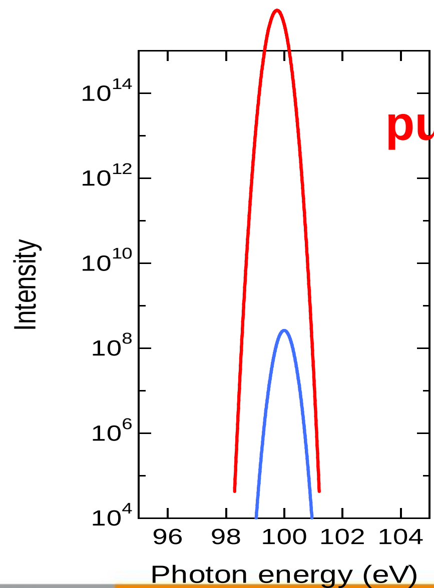
<u>Spindynamik:</u>
Molekular magnets und thin-layer solar sells

„Free electron“ light sources

Courtesy J. Feldhaus







Typical pulse energy ~1 mJ

Time-resolved experiments at BESSY II

Single – bunch mode:

~ 50 picosecond, 20 mA, 10^9 – 10^{13} ph/sec, 10 eV – 150 keV

α – mode :

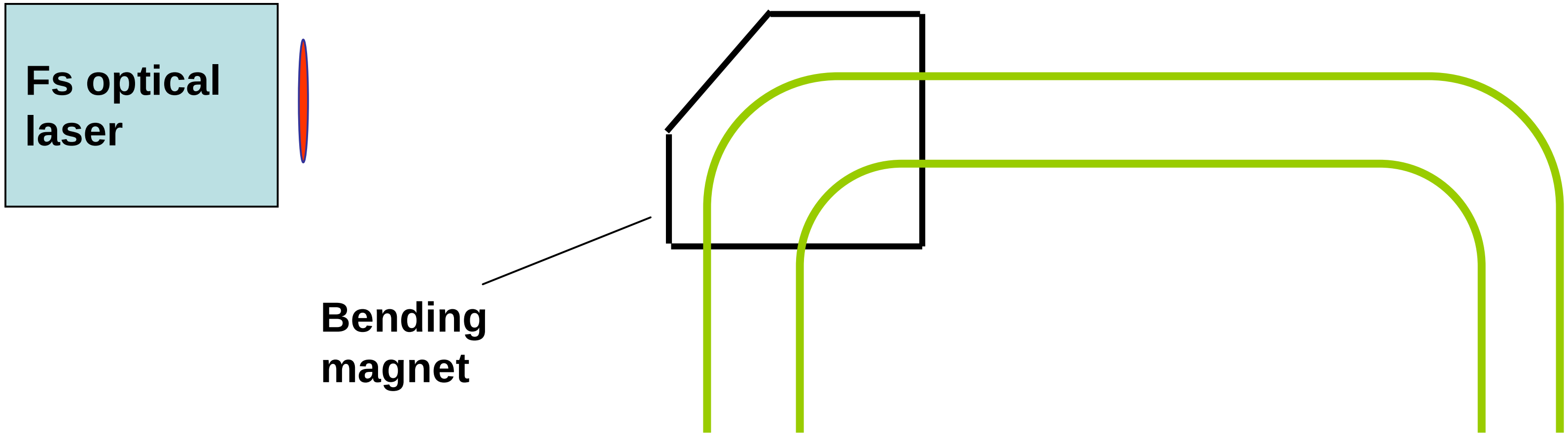
~ 1-10 picosecond, 2 mA, 10^6 – 10^8 ph/sec, 10 eV – 15 keV

Slicing undulator:

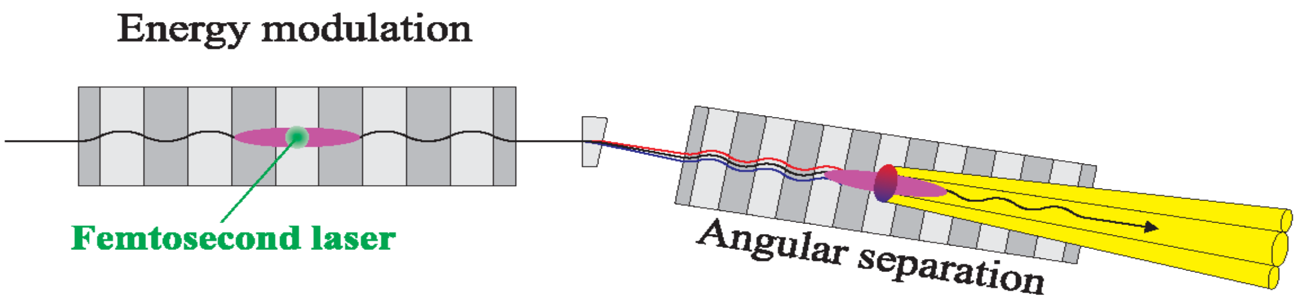
~ 0.1 picosecond, 10^7-10^8 ph/sec, 300 eV – 1200 eV in 5% BW

(10-100 ph/pulse)

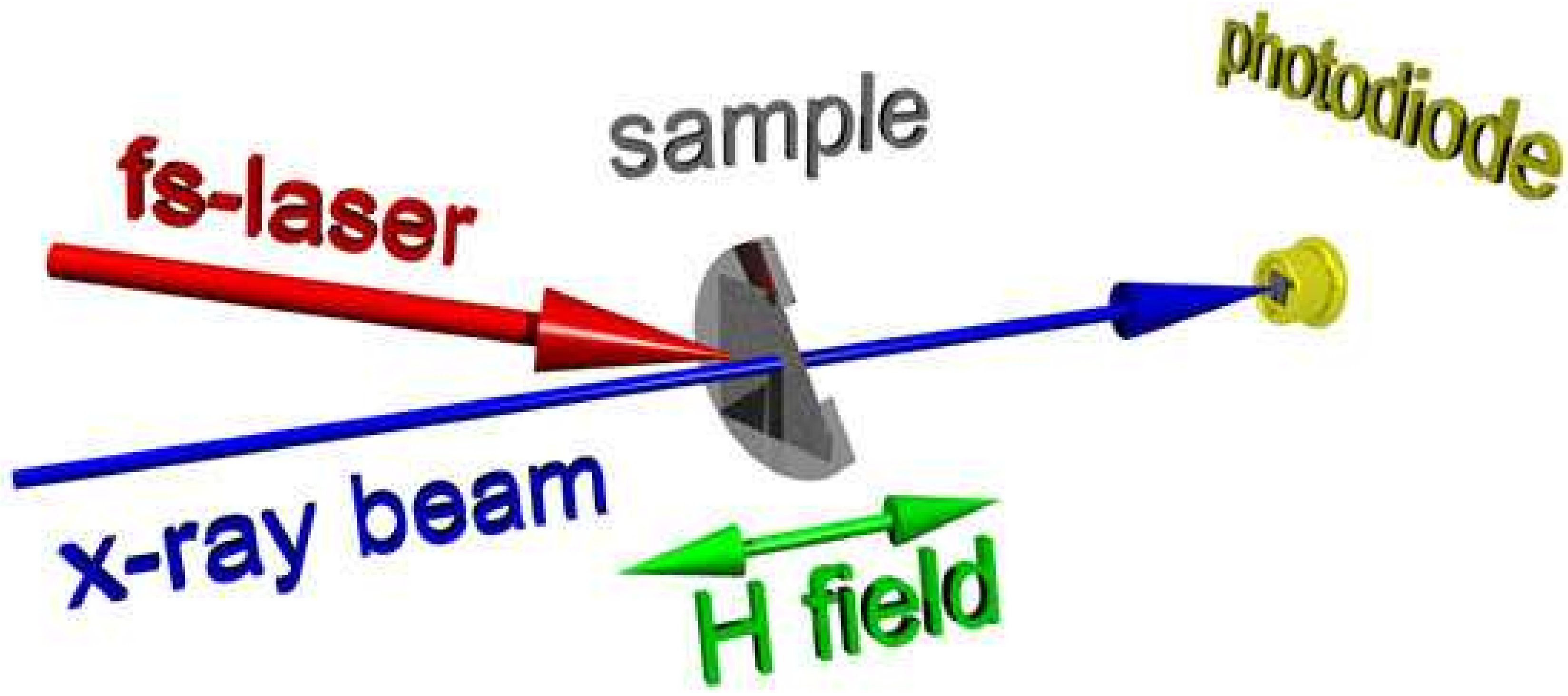
Principle of the „photon slicing“ method



- ALS pioneered fs slicing with signal : background ~ 1:1
- BESSY pioneered angular separation scheme with signal : background >10:1
- SLS (2006) and SOLEIL (~2008) will implement angular separation



Pump-probe experiemntal setup



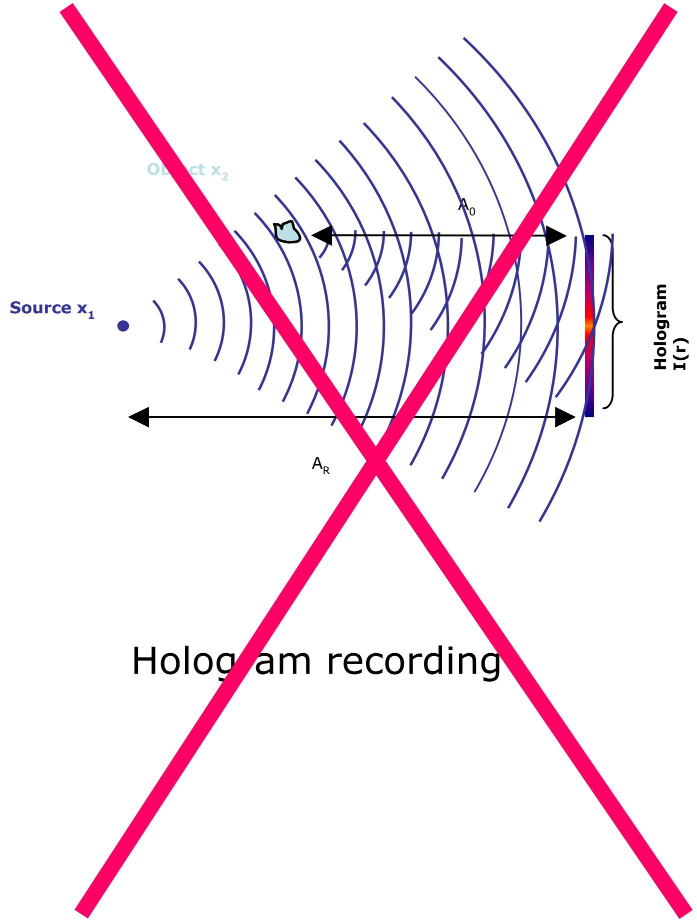
Femto-slicing optics

- Time delay in optics < 30 fs
- Maximum possible efficiency
- Parallel spectral measurements
- Bremsstrahlung blocking

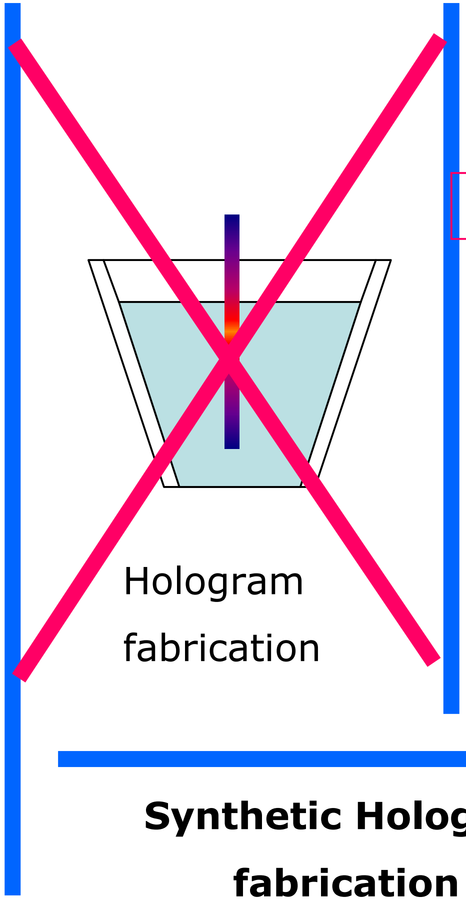
Optical element must combine:

Reflection + focusing + dispesion

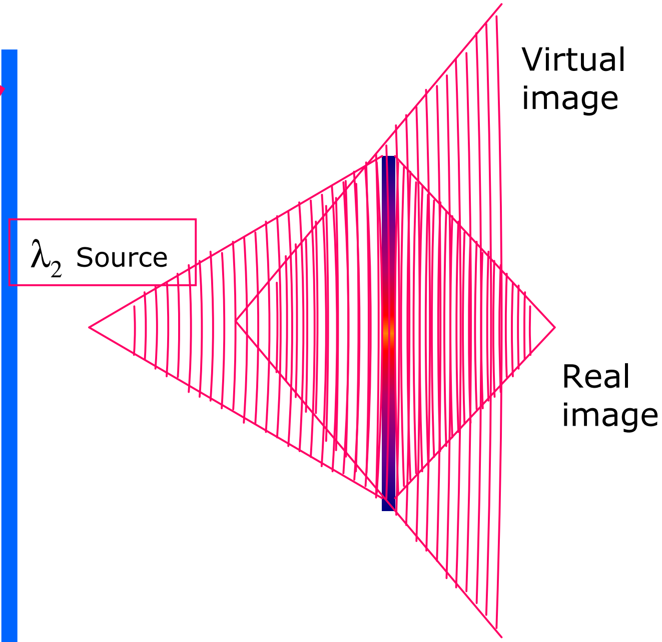
The main principle: Holographic process



Hologram recording



Hologram fabrication

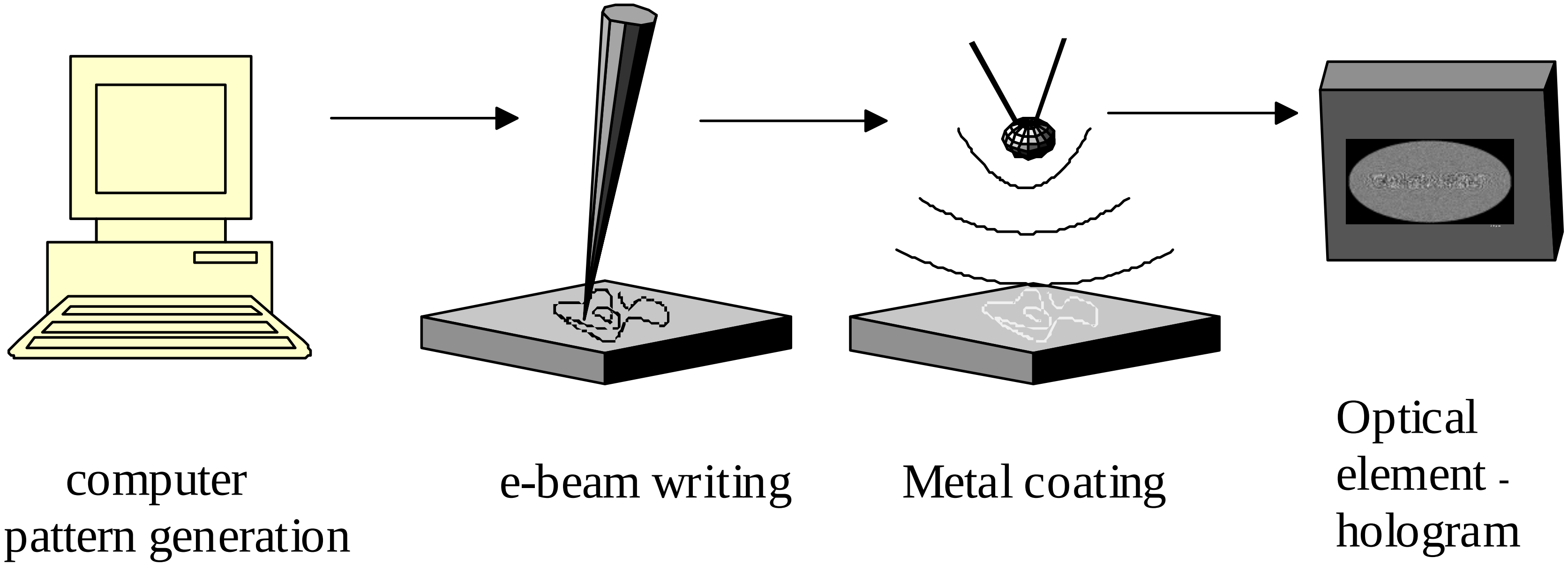


Hologram reconstruction

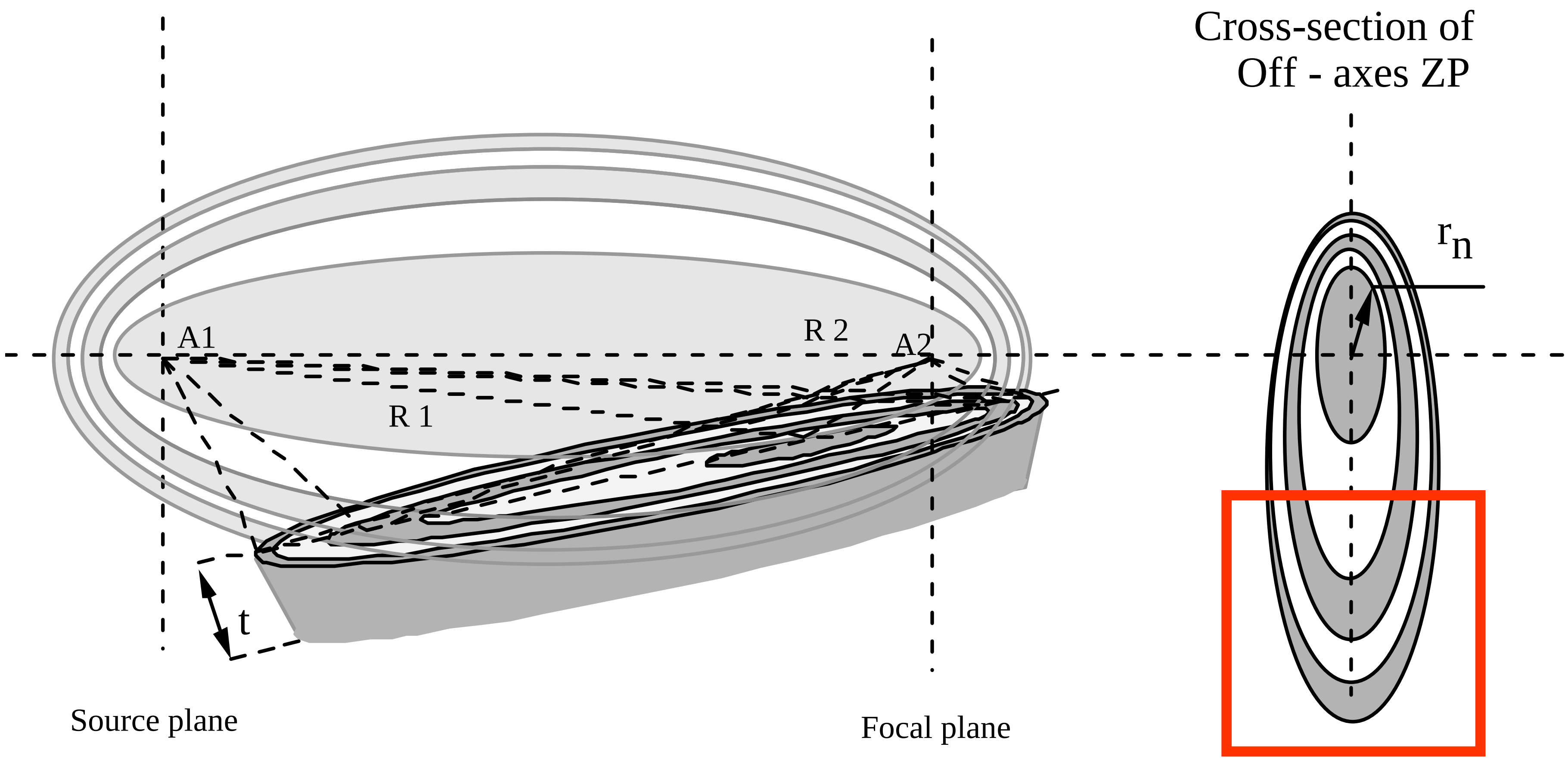
Synthetic Hologram fabrication

Holographic as X-ray optical element

Computer generated holographic optics



Elliptical Reflection zone plate (RZP)



Off-axis part of RZP

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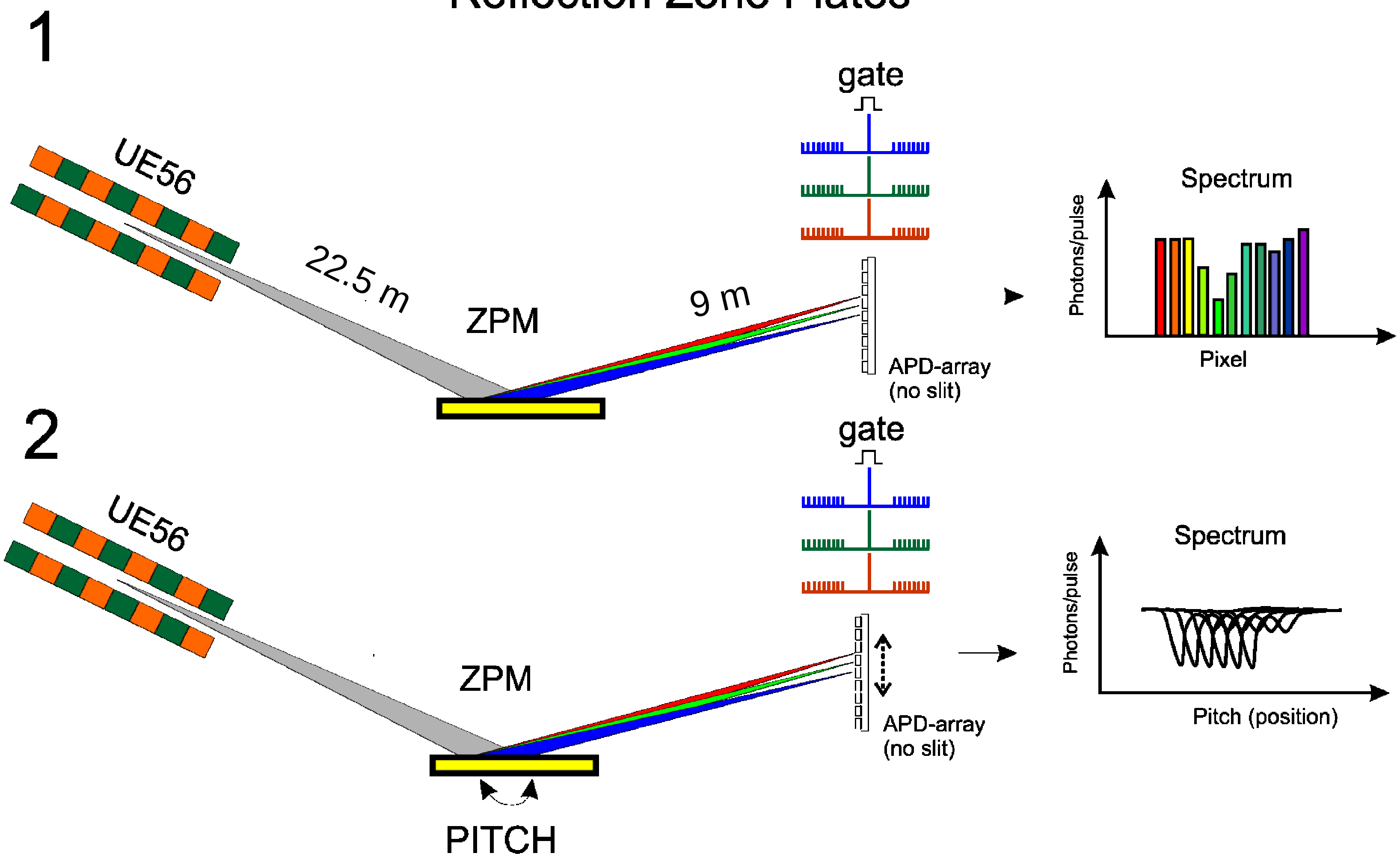
Time-Correlated Parallel detection with Reflection Zone Plates



Time resolution requieremnts

Requirements: the time delay in the optical element **< 30 fs.**

The number of periods in the diffraction structure:

$$N_{\max} = \frac{\Delta t_{pulse}}{\Delta t_{\lambda}}$$

where $\Delta t_{pulse} = 3 \cdot 10^{-14}$ is the X-ray pulse duration

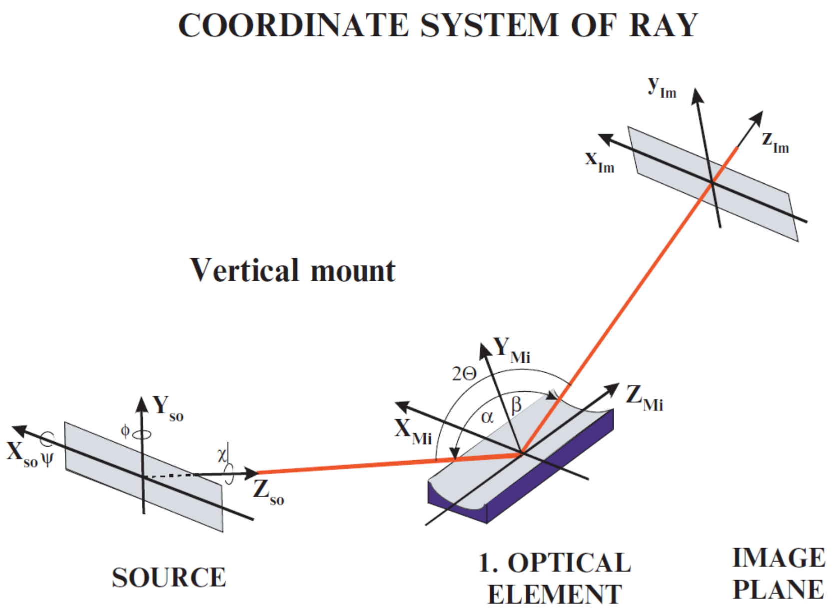
$\Delta t_{\lambda} = \frac{\lambda_{Fe}}{c} \approx 0.578 \cdot 10^{-17} s$ is the time delay for the Fe L-edge radiation (~ 710 eV)

The maximum number of grooves is **N_{max} < 5200.**

Maximum length of the optical element is **80 mm**

BESSY RAY program (F. Schäfers)

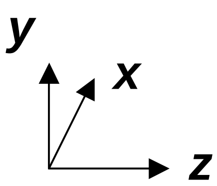
- Simulate Optical systems up to 10 elements
- Beamline design tool
- Geometric Optics
- Sources
  - Point
  - Dipole
  - Undulator
- Optical elements
  - Reflection Mirrors
  - Crystals (graded)
  - Gratings (VLS)
  - Transmission Zone Plates (cooperation Prague Uni. COST 2004 supported)
  - Reflection Zone plates (cooperation King's College London COST 2008 supported)

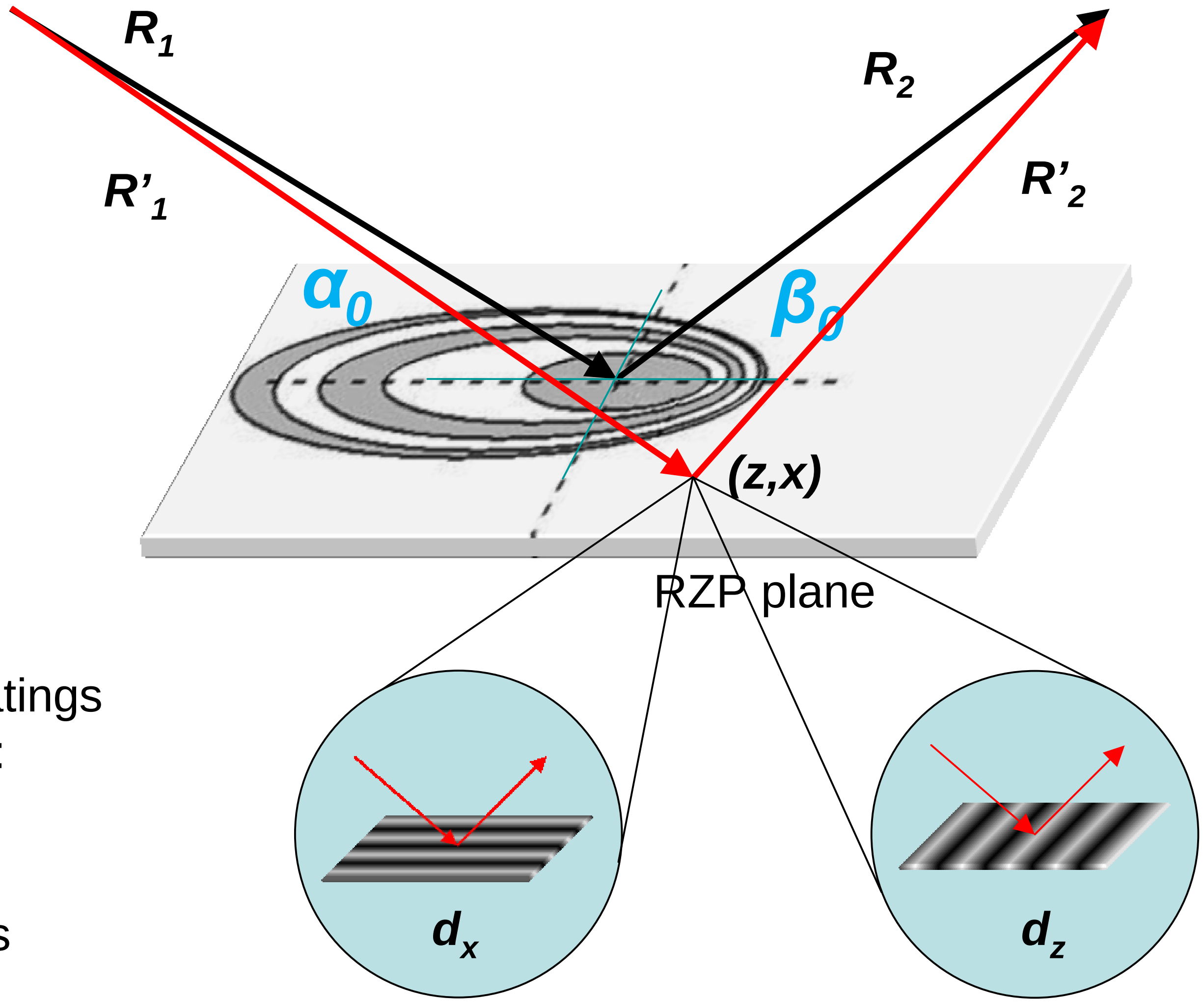


The main calculation principle

Courtesy Shahin Shahraei

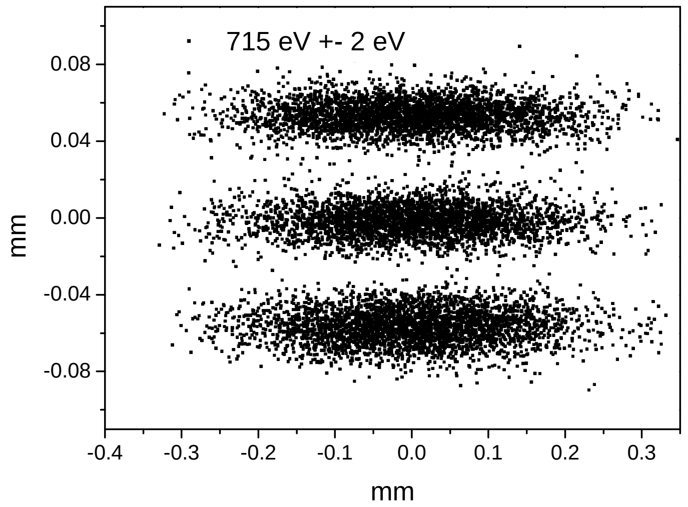
Raytracing code RAY for fs beamline calculation

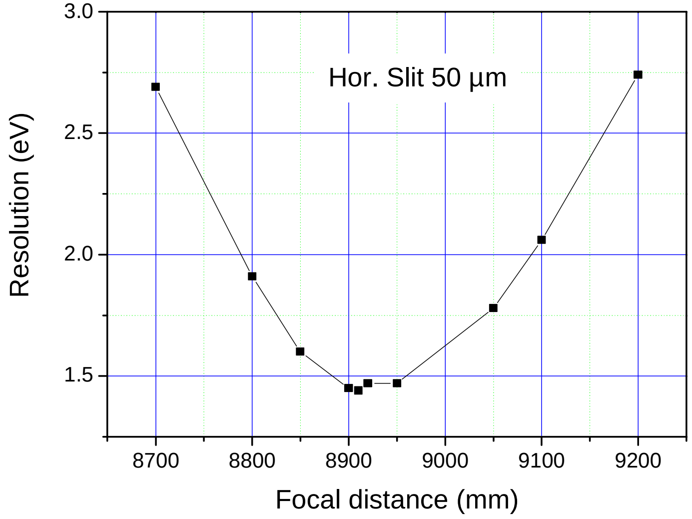


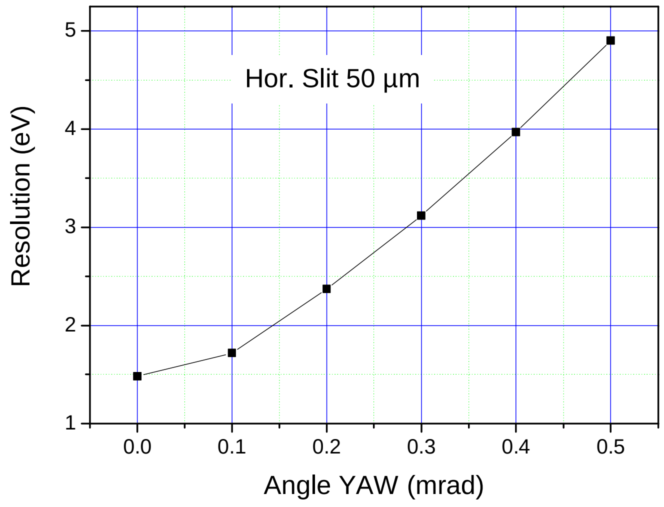


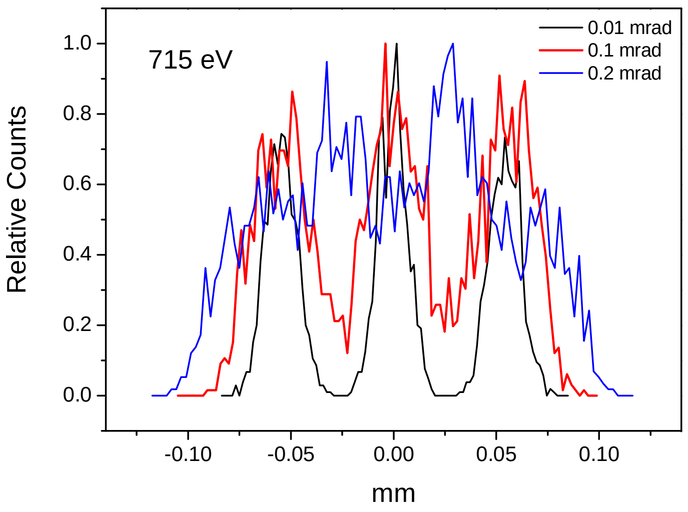
- Superposition of gratings
- Local grating vector:
  - d_x
  - d_z
- Decreases outwards

Raytracing code application: fs RZP focal plane

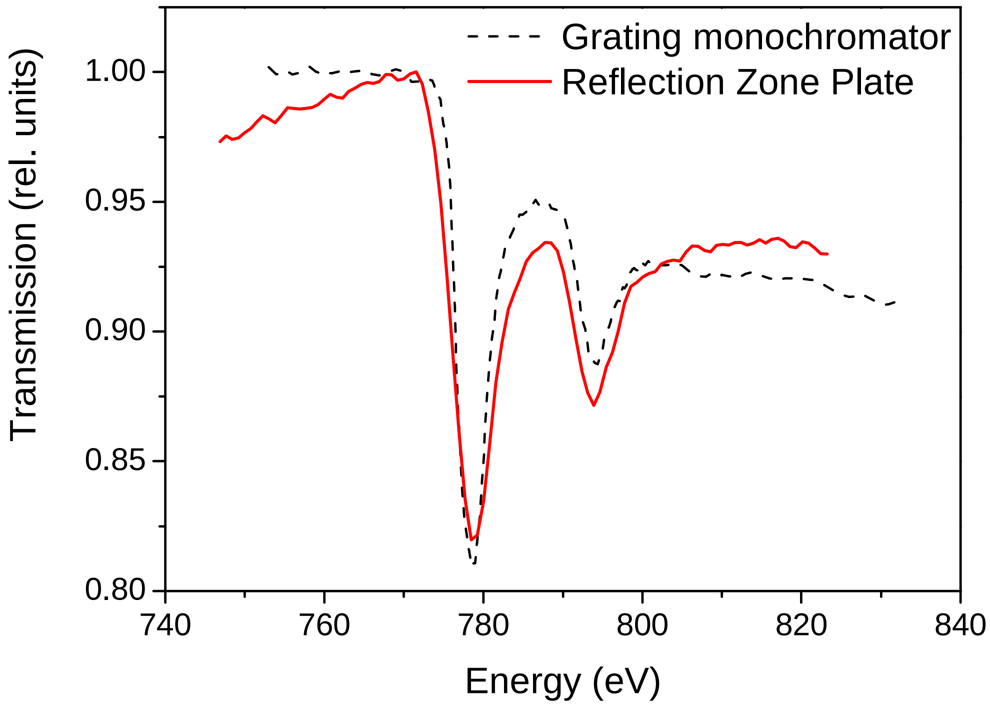


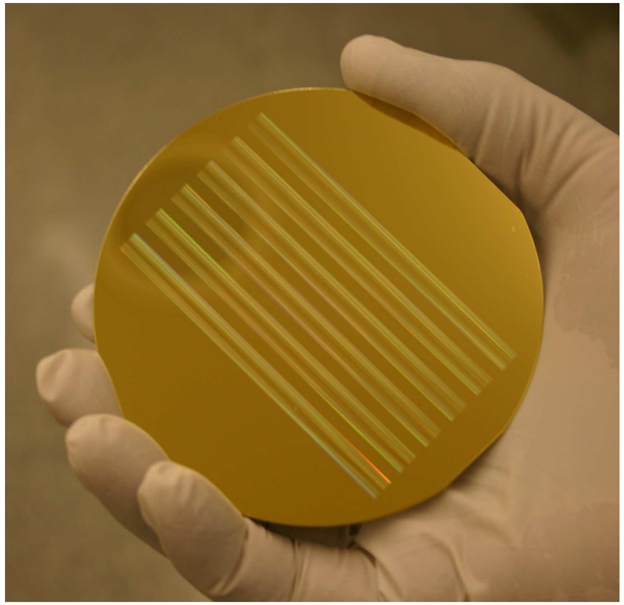






Combination on the same optical element the reflection, focusing and dispersion.





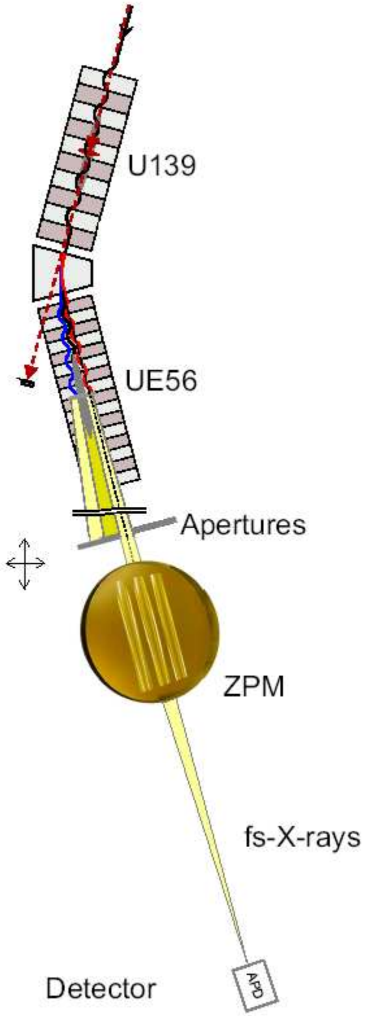
Gold reflection off-axis zone plates on a Si substrate: Focal distance: 902 cm. Outer zone: 1 µm. Aperture: 80 mm x 10 mm

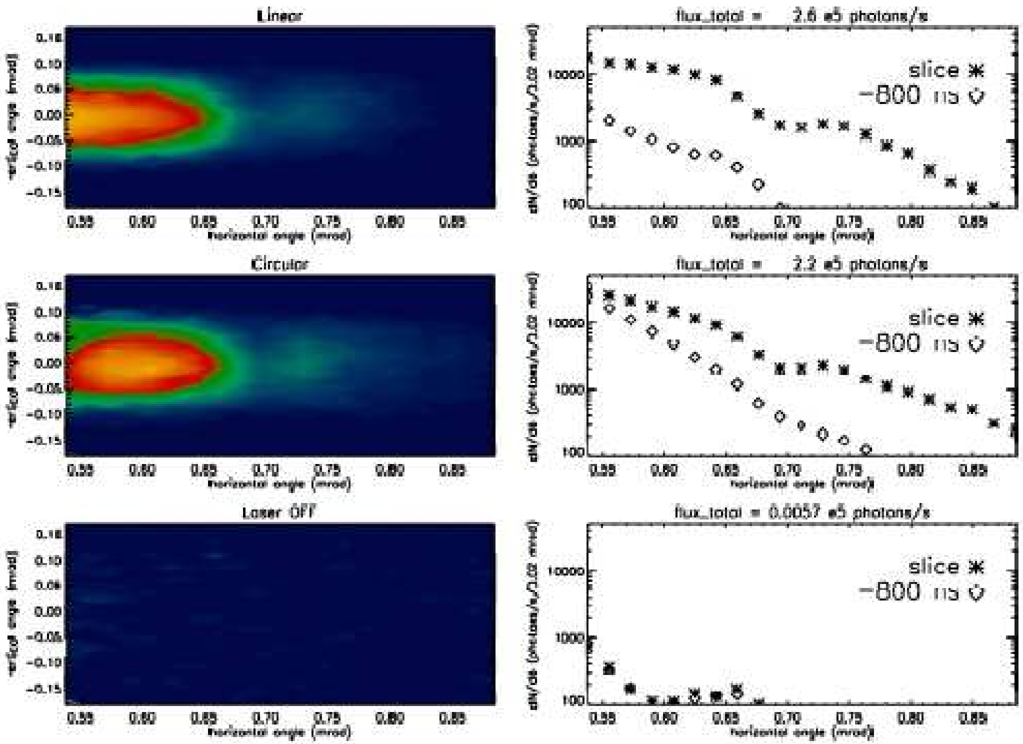
Lenses groove depth is 8 nm.

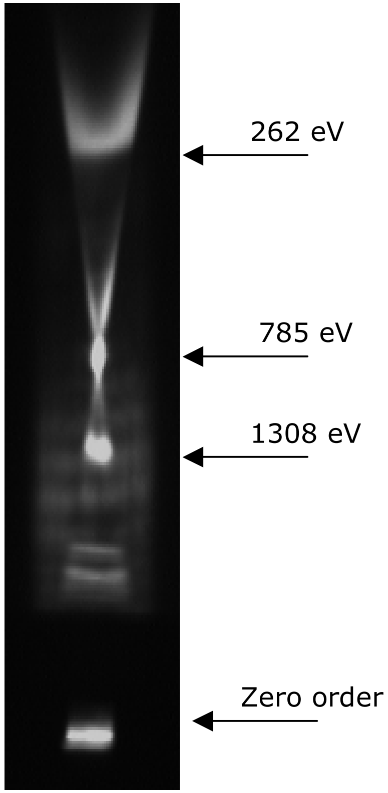
Absorption spectrum of Co foil 40 nm thick

The flux is 10 times higher as grating monocromator

Reflection Zone Plates map sliced photons

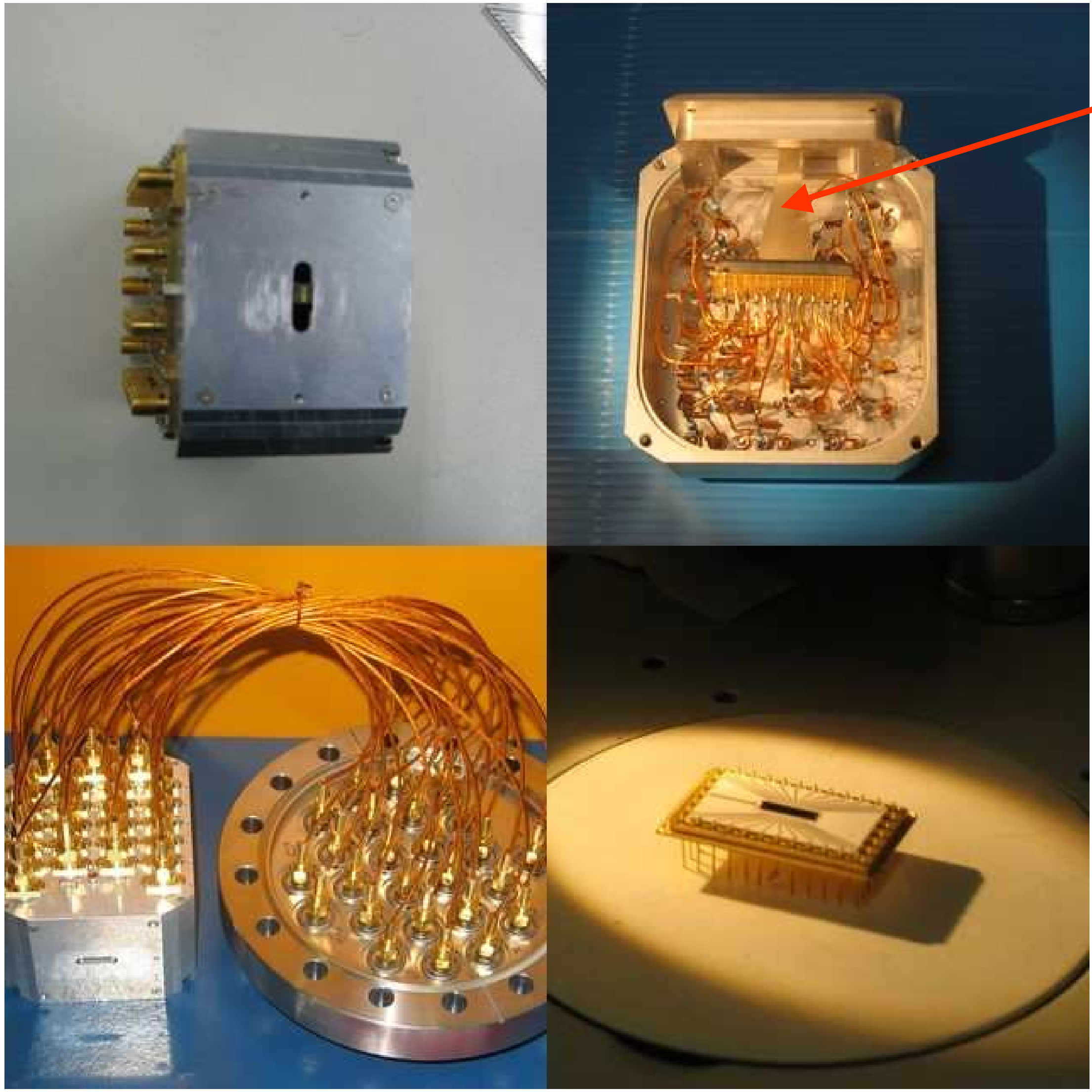




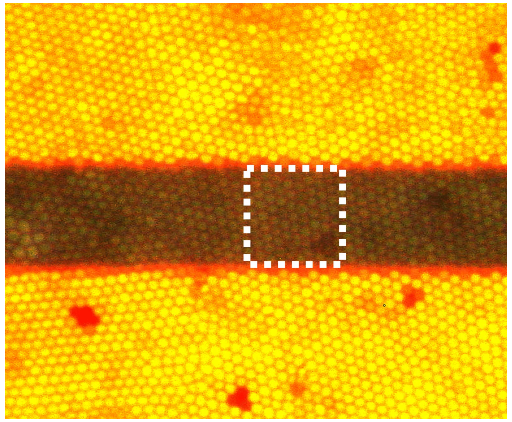


Beamline optics focal spot: ~ 300 µm (H) x 25 µm (V)
Energy dispersion in focal plane: ~ 40 eV / mm
Total beamline optics transmittance: ~ 6.5%
Time resolution of beamline optics: ~ 30 fsec

Parallel detector for fs beamline

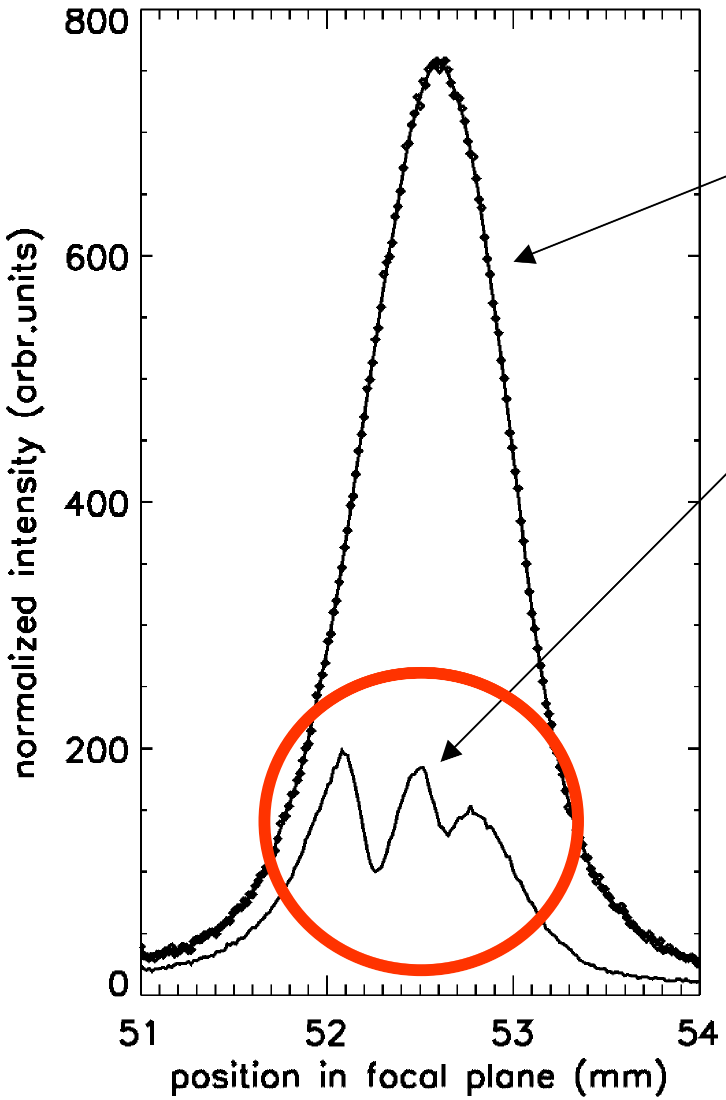


Optical fiber



Parallel detector array consists of 25 avalanche diodes, 300 x 300 µm^2 each. Optical fiber is used to emprove resolution down to 50 x 50 µm^2.

XANES with fs time resolution



3rd harmonics from the UE56 without foil

30 nm Ni-foil transmission spectrum

Transmission spectra from a 30 nm Ni thin film. A single-pixel APD-signal, being gated on the hybrid-bunch, while the detector was moved along the dispersion plane. The 3rd harmonics from the UE56 with (dots) and without the Ni-foil (line) in the beam path.

Time-Resolved XMCD on Ni film

Courtesy C. Stamm

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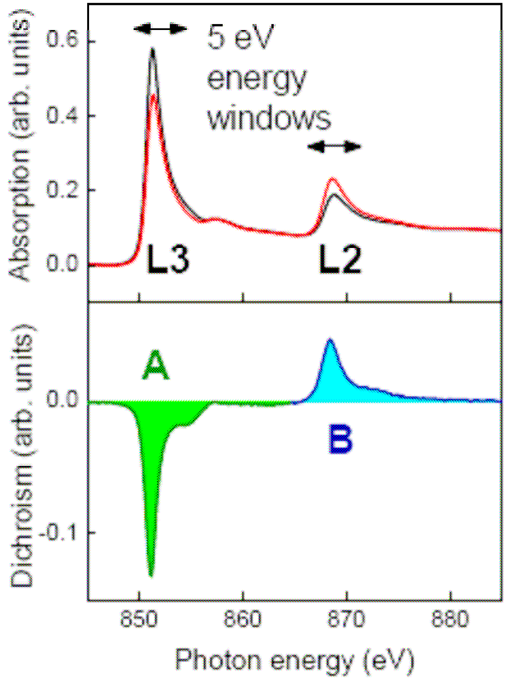
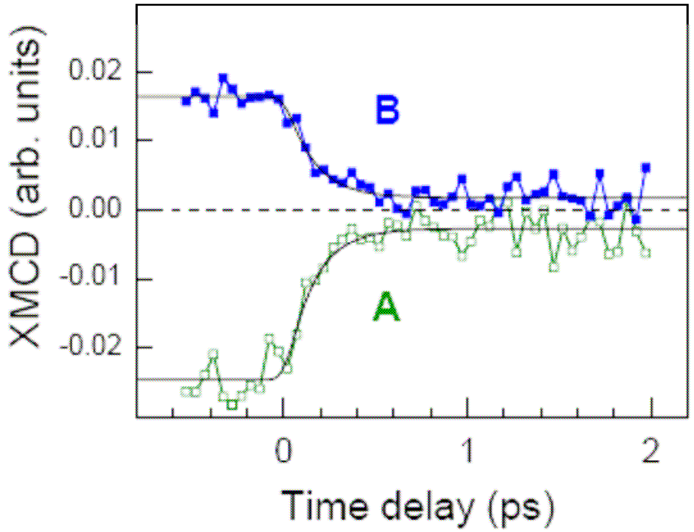
Ni dichroism spectrum
(equilibrium, high resolution)



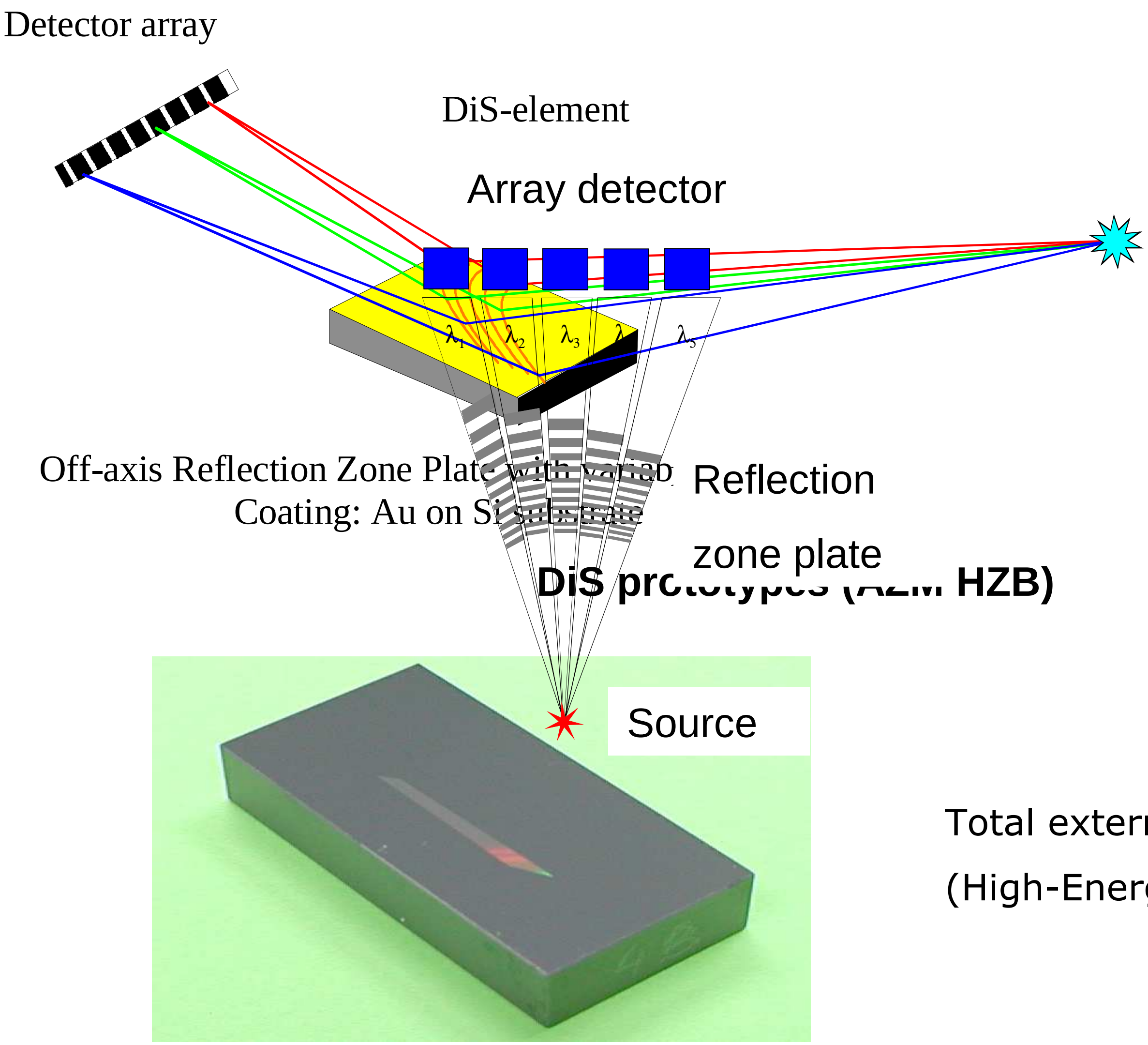
fs time-resolved dichroism
(energy window ≈ 5 eV)



τ **= 150 ± 50 fs**

fit with exponential decay
(same for A, B)

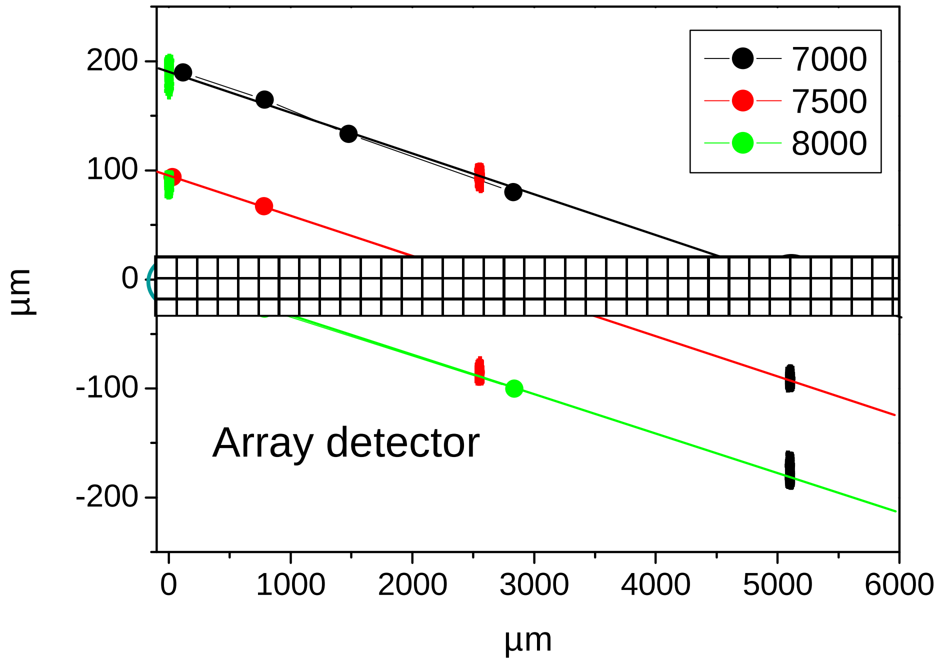
Parallel X-ray Diffraction Spectrometer (DiS)

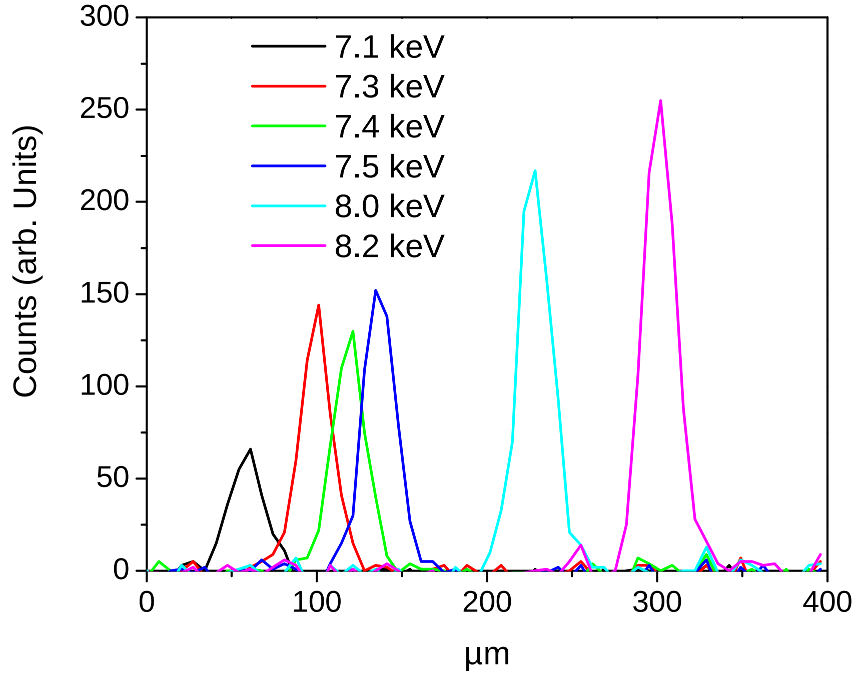


Total external reflection structure

(High-Energy DiS)

DiS tests in the energy range of 7100 eV – 8200 eV



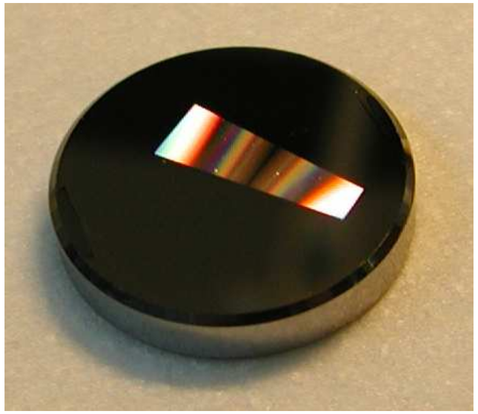


The dispersion of the parallel diffraction spectrometer DiS for the energy range between 6 and 8 keV.

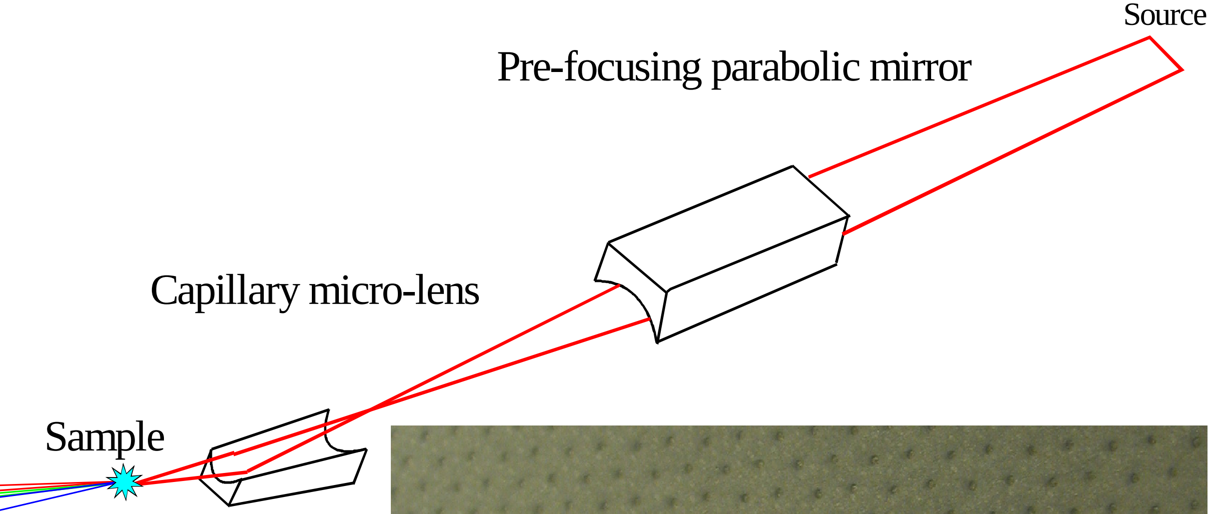
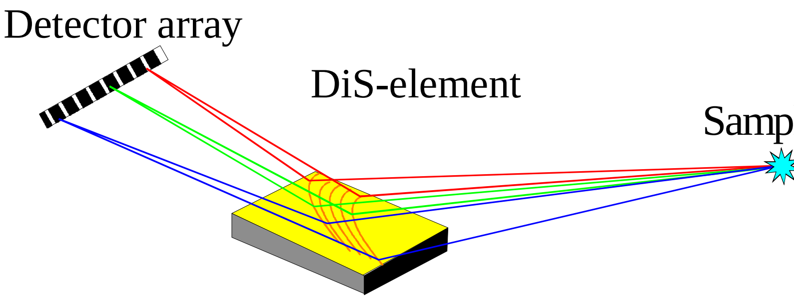
Resolution test of a parallel diffraction spectrometer (DiS) element for the energy range between 6 and 8 keV

Nano-focusing with capillary micro-lens

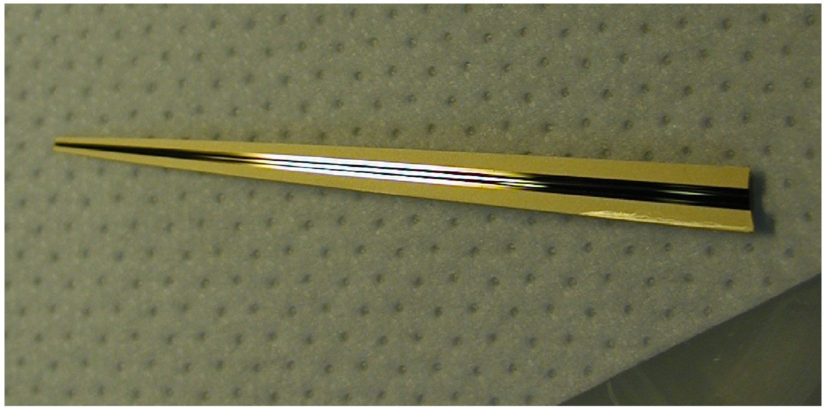
Reflection structure: Low-Energy DiS



Focal spot 100 nm possible

Off-axis Reflection Zone Plate with variable spacing. Coating: Au on Si substrate



Monocapillary micro-mirror. Au coated.

Acknowledgments:

A. Firsov, F. Siewert, F. Schäfers,

K. Holldack, H. Dürr, C. Stamm, N. Pontius

I. Packe, Ch. Kalus, T. Kachel

AZM – Centre for Microtechnology, HZB

W. Eberhardt

Thank you!