Time-resolved x-ray microscopy

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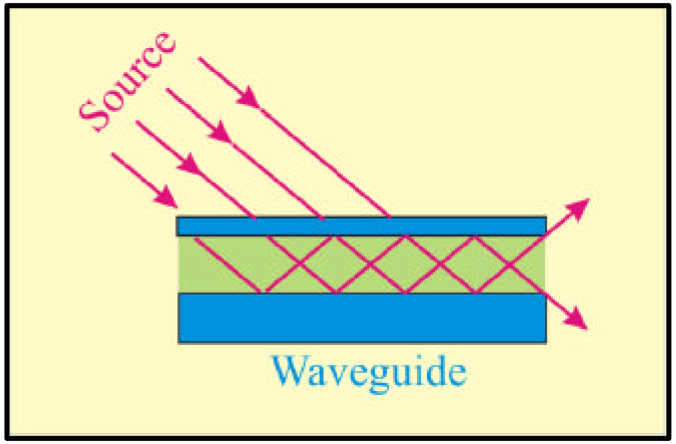
Outline

- X-ray waveguide (WG)
    - Spatial properties
    - Efficiency
    - Temporal properties
- Experimental microscopy schemes
    - Imaging
    - Photon correlation spectroscopy
    - Coherent scattering

X-ray Waveguide

Resonant beam coupling



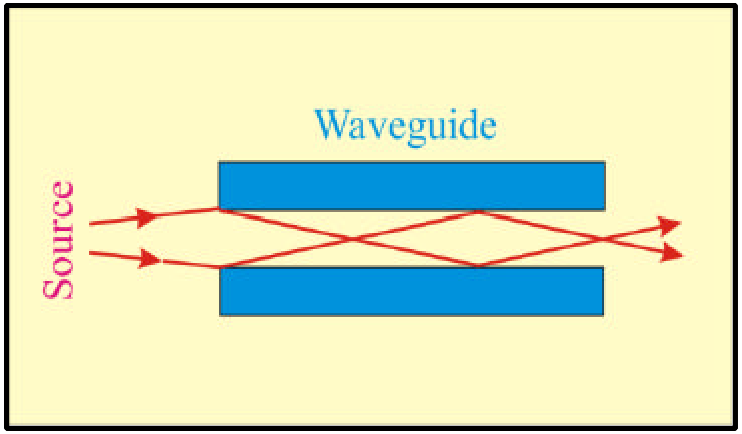
• Efficient compression of x-rays inside core

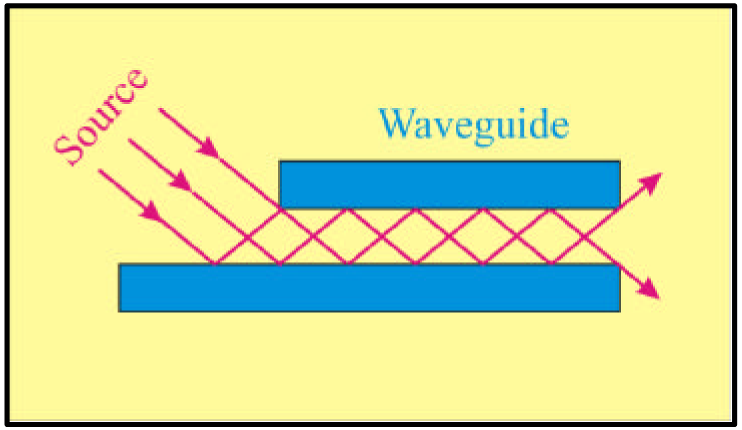
• Spatial and coherence filtering of incoming radiation

• Suitable for soft x-ray FEL radiation:

- Possibility of cooling
- Low absorption

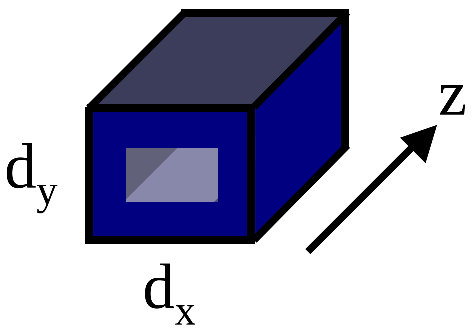
Front-coupling





Mode structure

Internal field distribution is the ***exact*** solution of Helmoltz equation with suitable boundary conditions:

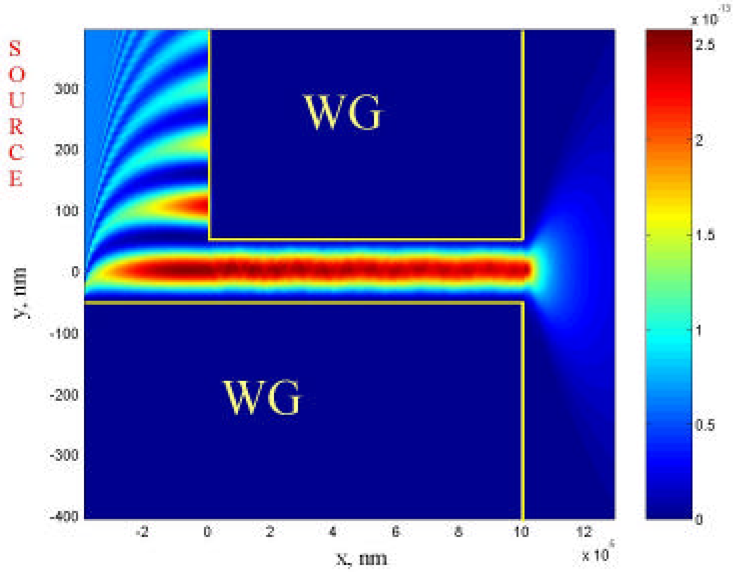


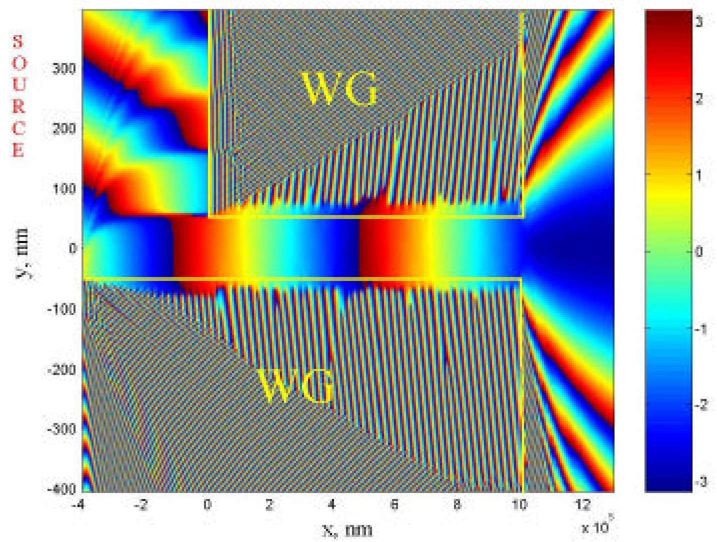
$$\tan\left[\frac{1}{2}\left(k_m d - (m-1)\pi\right)\right] = \frac{\sqrt{\cos^2\theta_m - \cos^2\theta_c}}{\sin\theta_m}$$

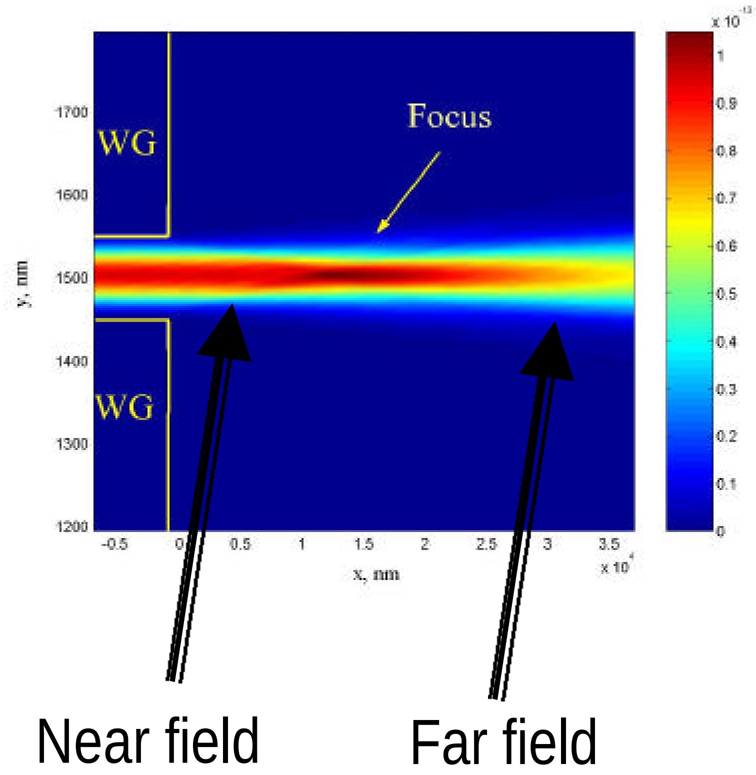
$$k_m = \frac{2\pi}{\lambda}\sin\theta_m$$

$$k_z = \frac{2\pi}{\lambda}\sqrt{1 - \sin^2\theta_m - \sin^2\theta_n}$$

1^{st} mode calculation







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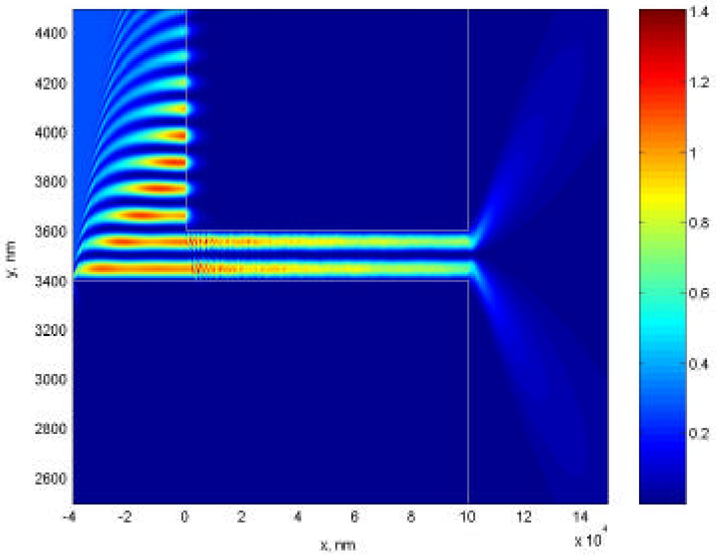
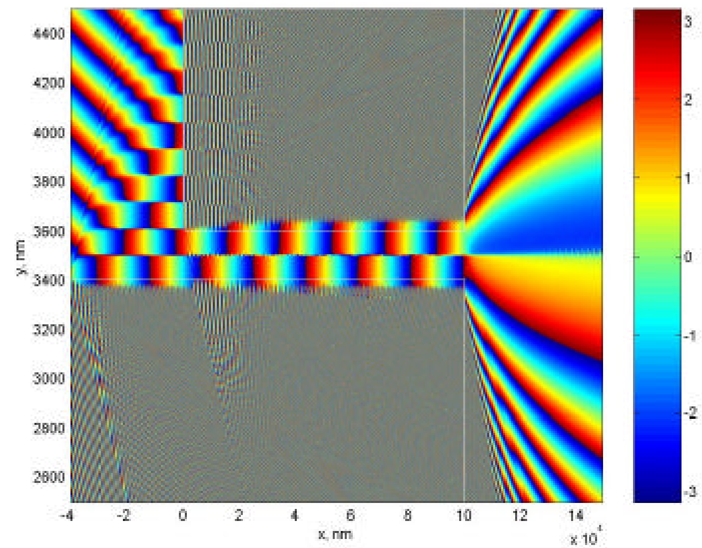
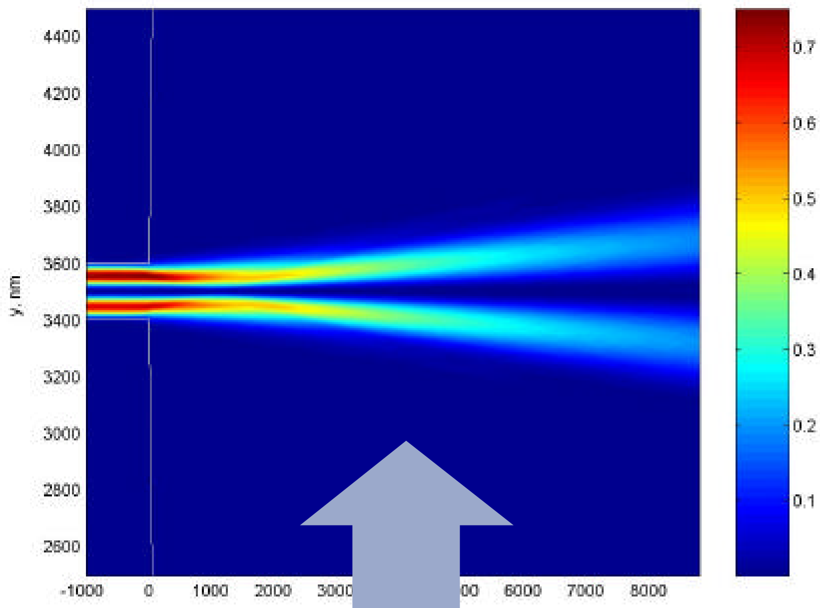
2^{nd} mode calculation







BEAM SPLITTING

Efficiency [1]

Acceptance

The phase space coherence volume for a radiation beam represented by gaussian distribution functions in *spatial* and *angular* extend

$$A * \Delta\phi \approx 0.44\lambda$$

1D WG can accept a coherence volume

$$d * \Delta\phi \approx 0.44\lambda$$

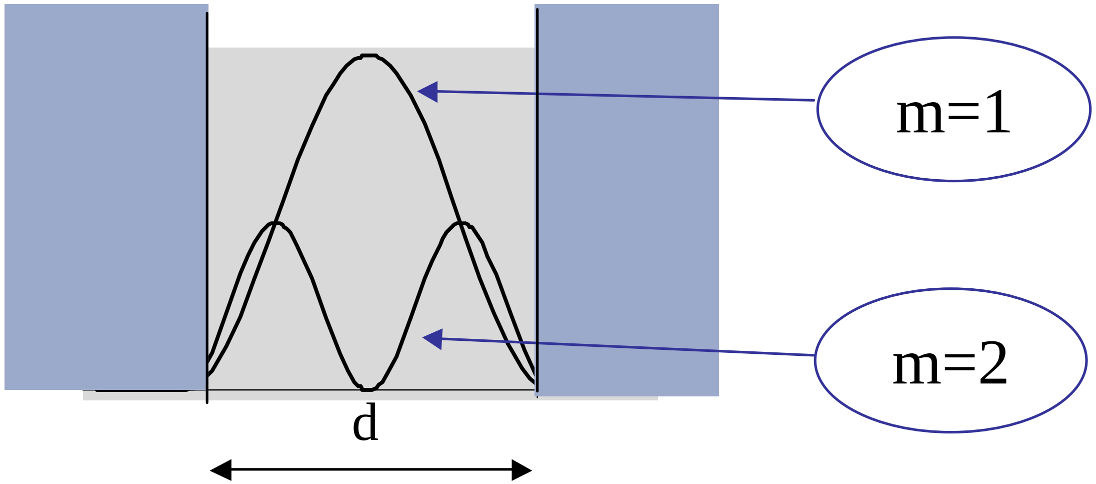
⟹ Angular acceptance

W. Jark and S. Di Fonzo, *J. Synchrotron Rad.* **11**, 386 (2004)

Efficiency [2]

Transmission

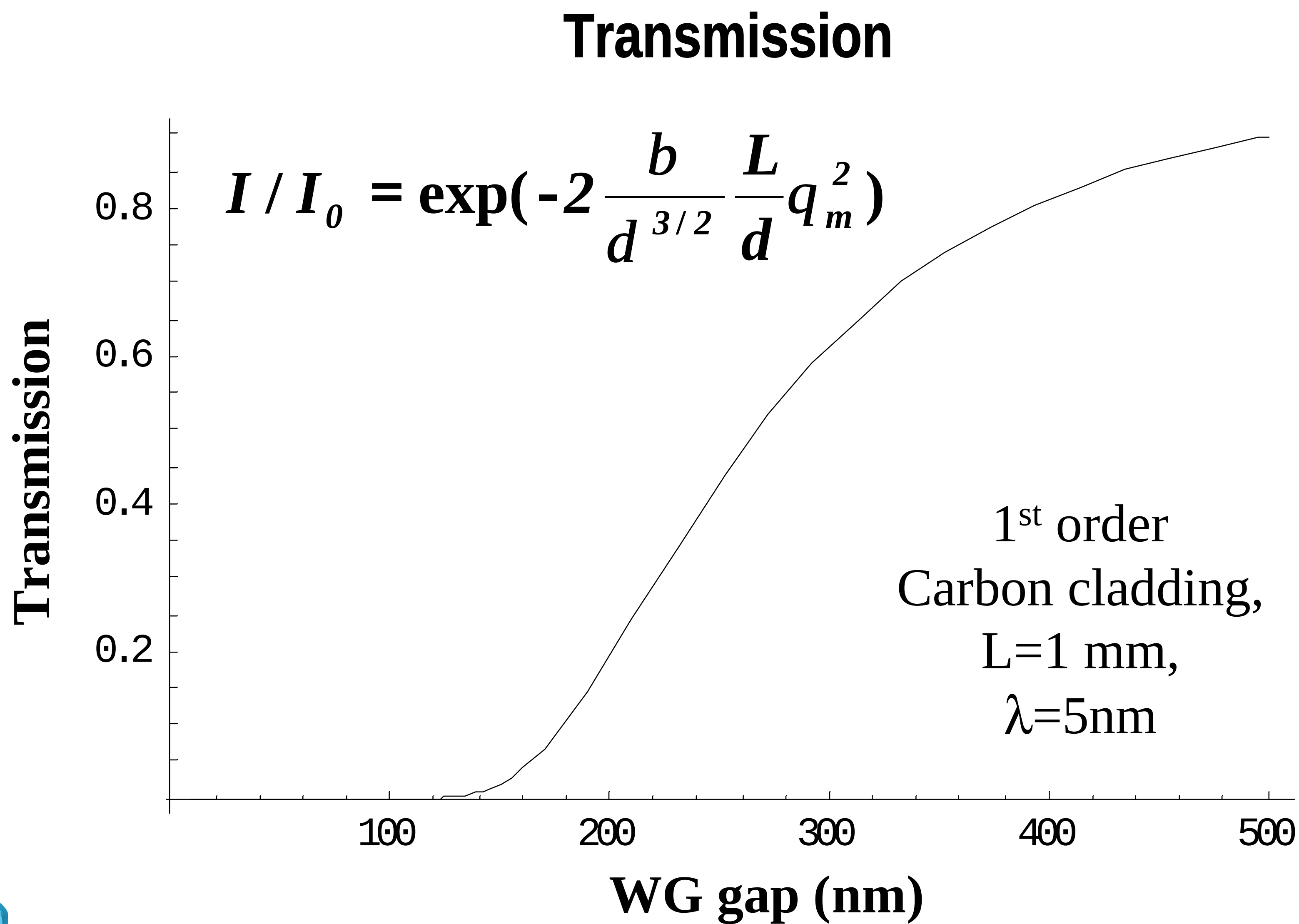
Guided radiation is absorbed in the cladding layers.



Absorption length for λ=5nm and d=400nm

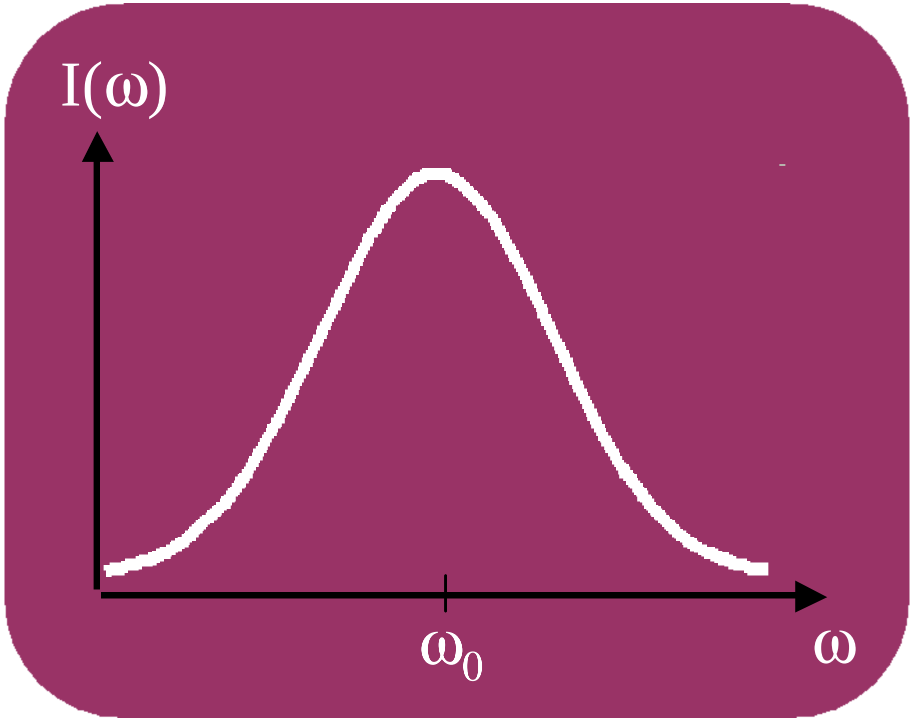
Material	Mode 1	Mode 2	Mode 3
C	7.5 mm	1.9 mm	0.83 mm
Si	0.84 mm	0.21 mm	0.09 mm

Efficiency [3]



Dispersion [1]

Pulse with central frequency ω_0,

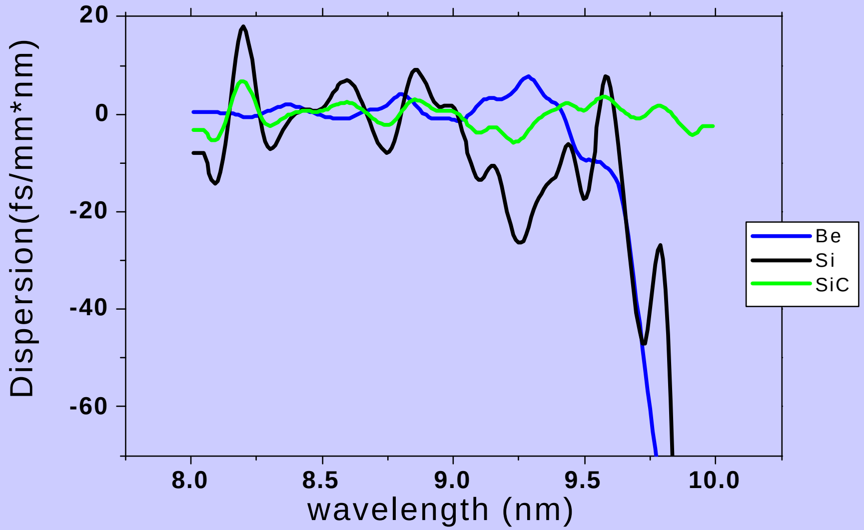


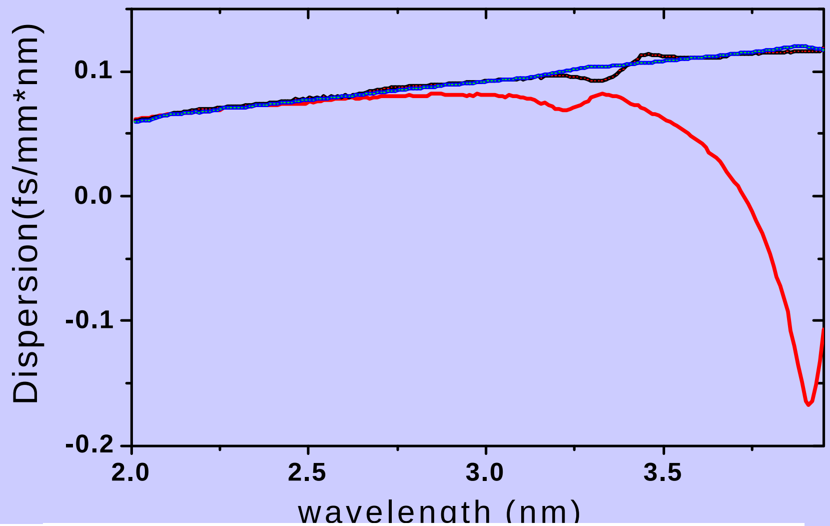
$$k_z = \frac{2\pi}{\lambda}\sqrt{1 - \sin^2\theta_m - \sin^2\theta_n}$$

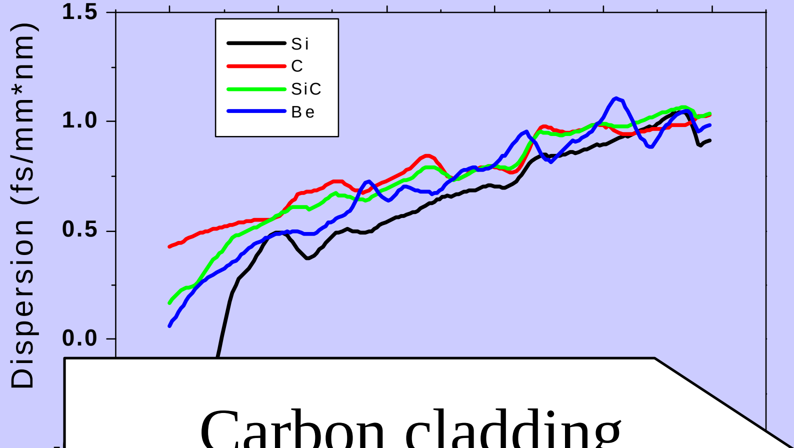
$$GVD = \left.\frac{\partial^2 k_z}{\partial \omega^2}\right|_{\omega_0} = k_z''$$

$$D = \frac{\partial k_z'}{\partial \lambda} = -\frac{2\pi c}{\lambda^2} GVD$$

Dispersion [2]

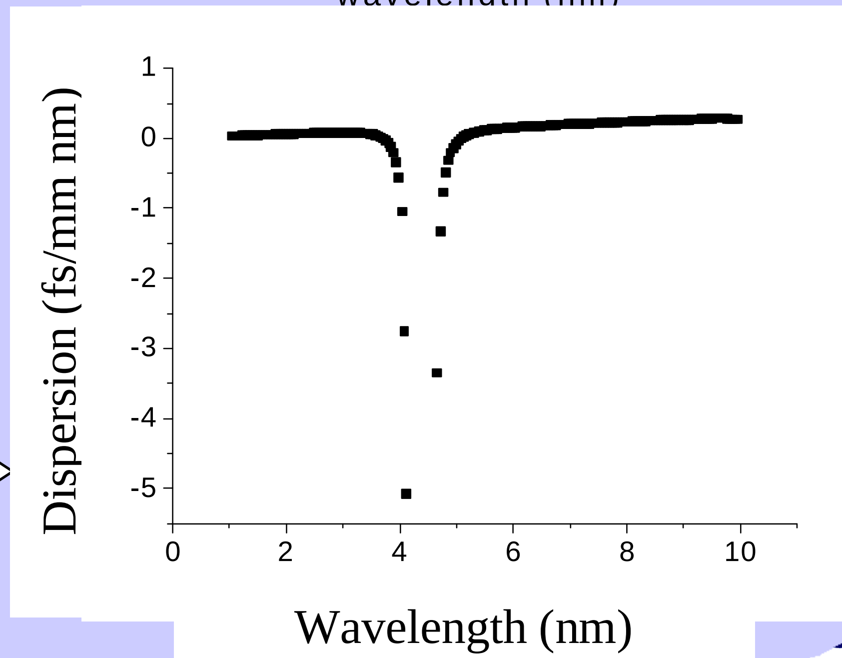




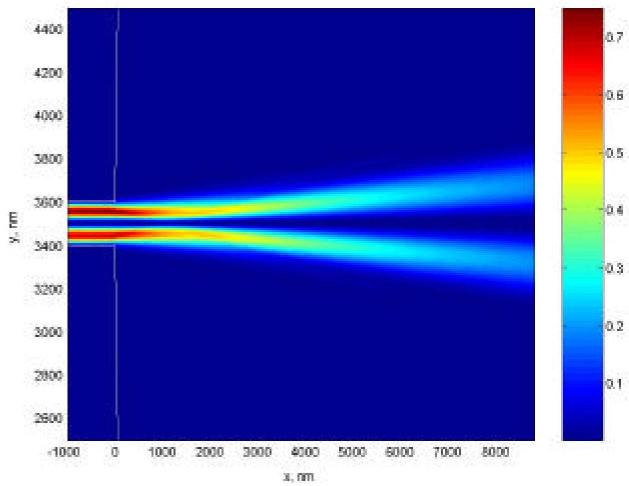


Carbon cladding

Gap: 200x200 nm^2



Beam splitter



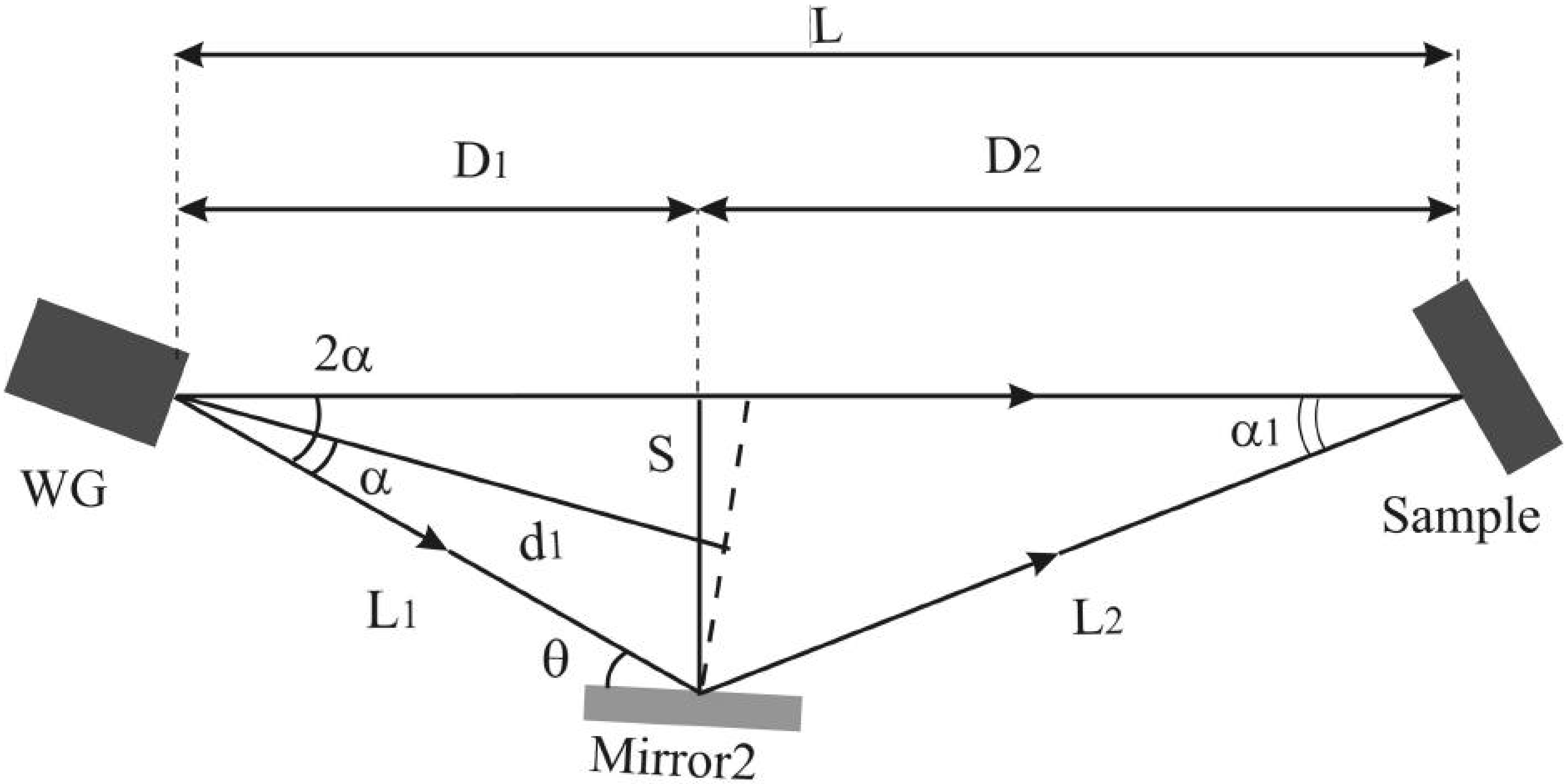
In condition of small dispersion

One optics

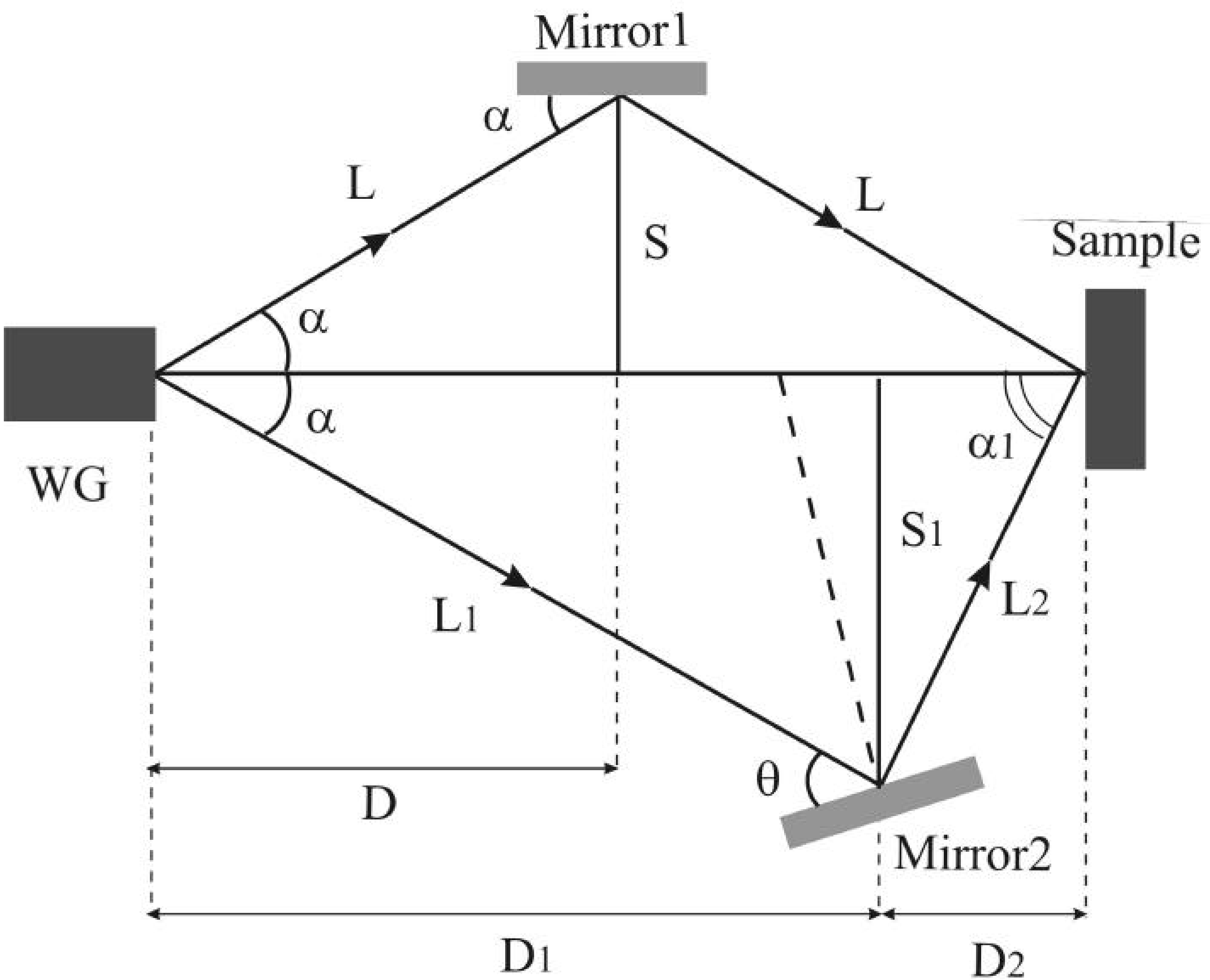
- No-perturbation of FEL temporal structure
- Nano spatial resolution
- Spatial and coherence filtering of radiation
- Two coherent beams

- X-ray waveguide (WG)
  - Spatial properties
  - Efficiency
  - Temporal properties
- Experimental microscopy schemes
  - Imaging
  - Photon correlation spectroscopy
  - Coherent scattering

Experimental scheme [1]

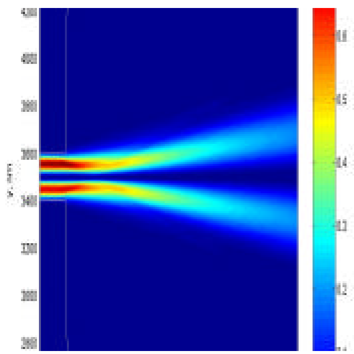


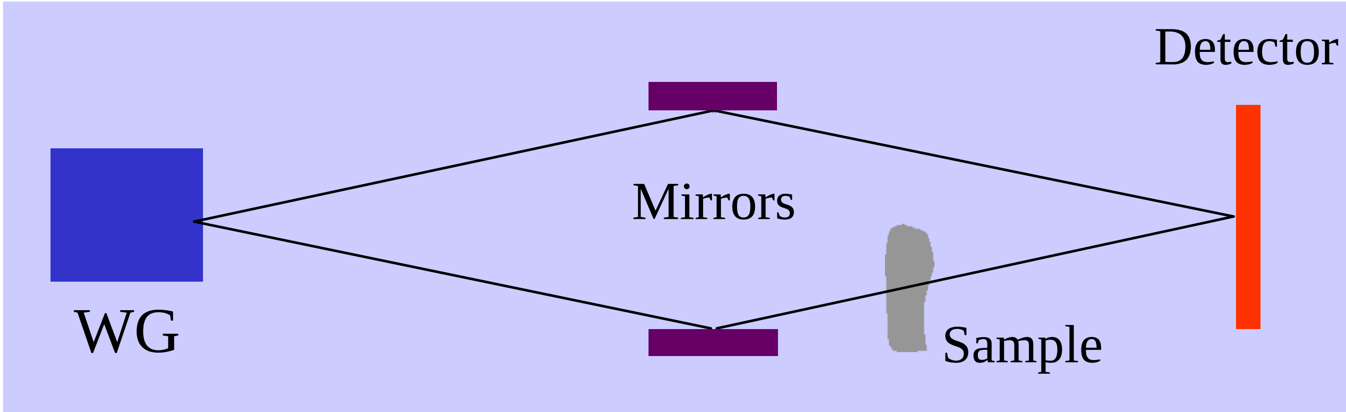
Experimental scheme [2]



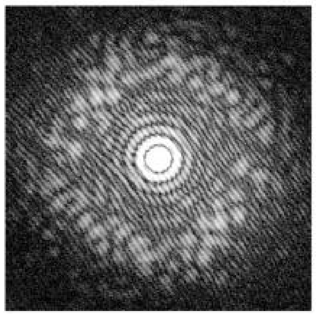
Lensless imaging

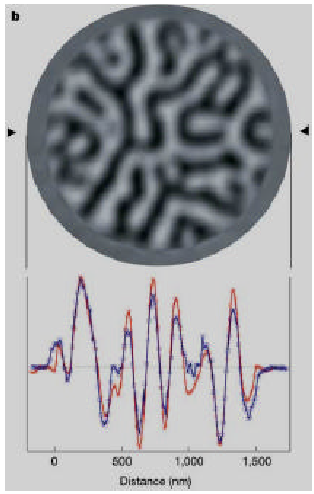
Single shot holography





Magnetic domains in a Co/Pt multilayer



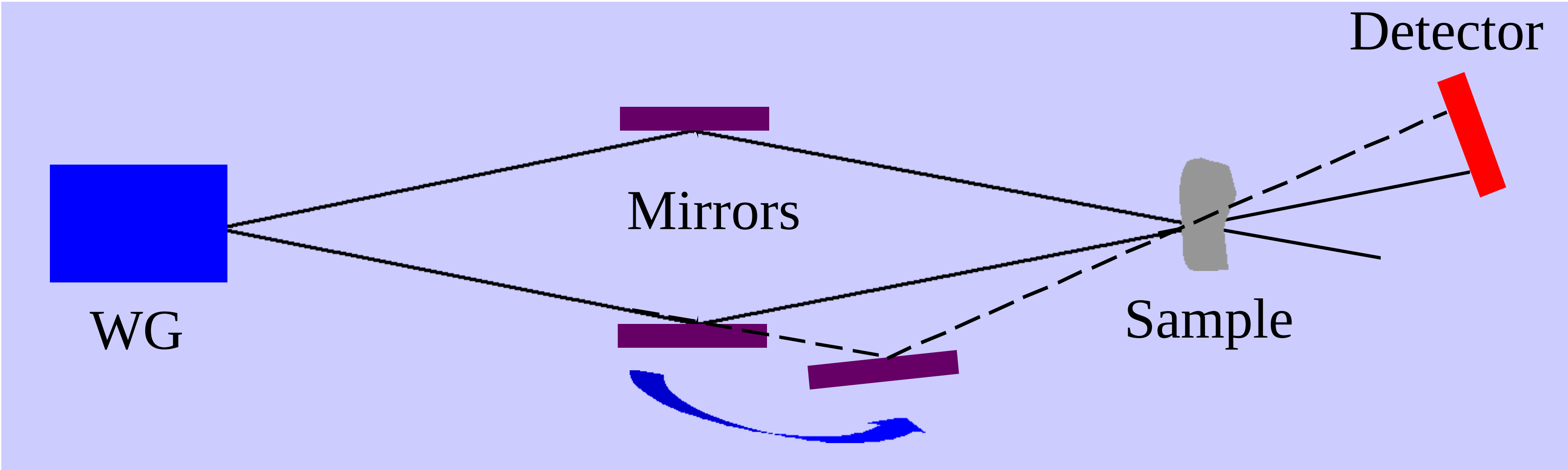


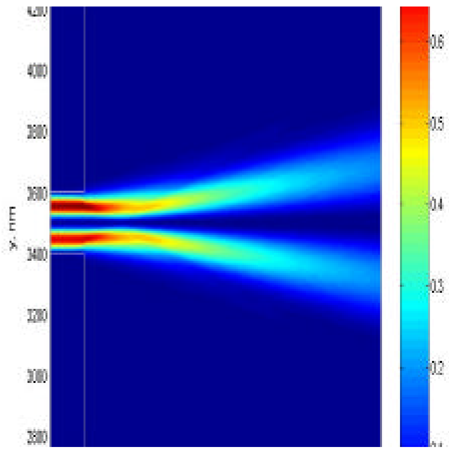
Exploiting coherence, complete phase information is accessible. Short pulse duration, allows single shot measurements with high spatial resolution.

S. Eisebitt et al., *Nature* **432**, 885 (2004)

X-ray pump/X-ray probe

Time-resolved microscopy



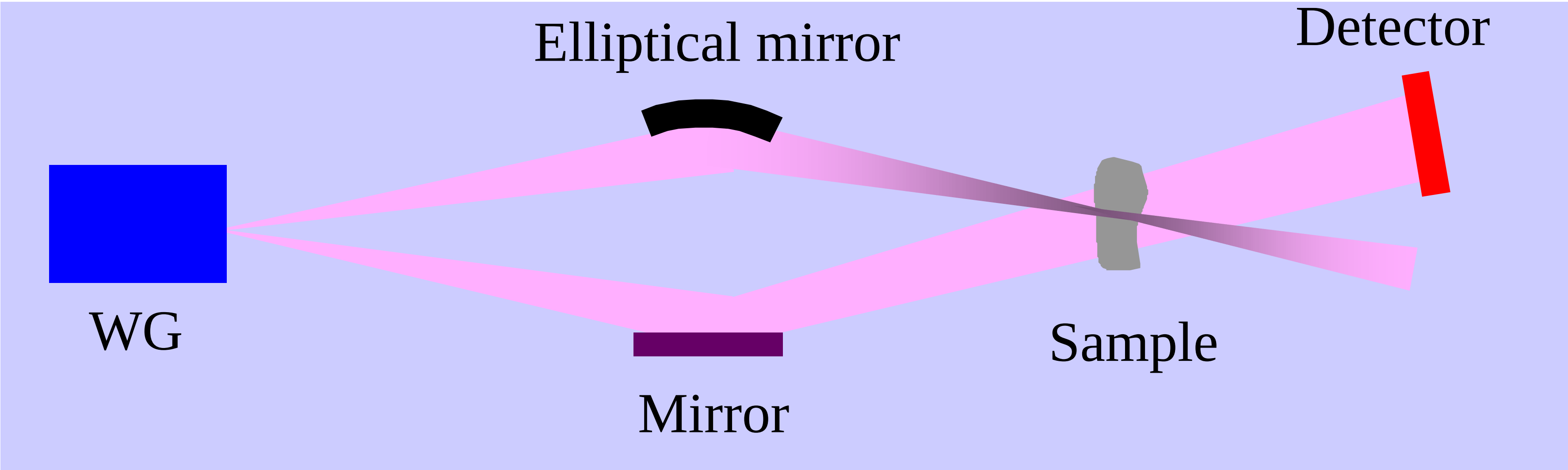


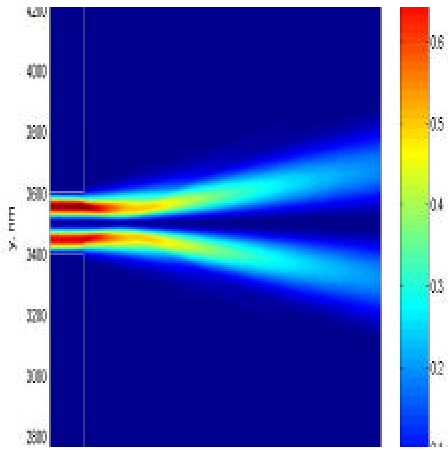
Variable delay allows the study of transient phenomena in projection microscopy

No need of synchronization

X-ray pump/X-ray probe

Time-resolved microscopy



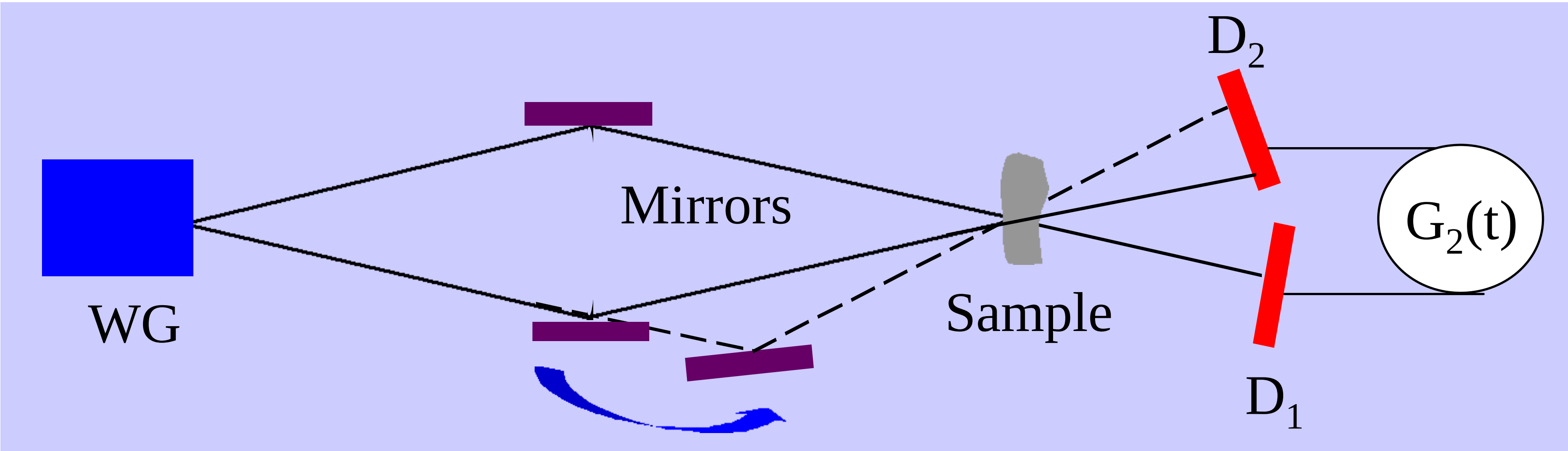


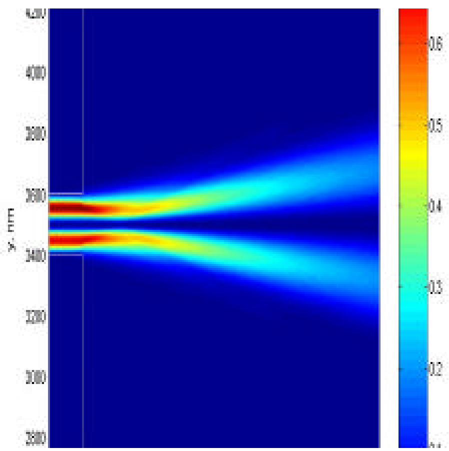
Radiation damage

High resolution detectors
⟶ F. Bonfigli

X-ray pump/X-ray probe

Photon correlation spectroscopy

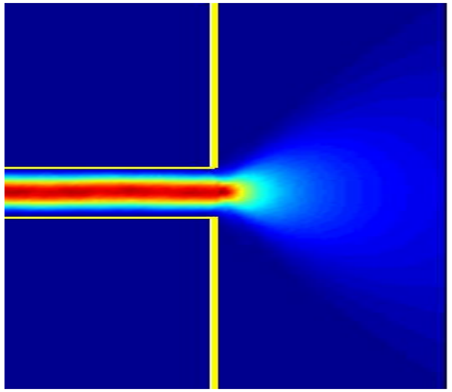


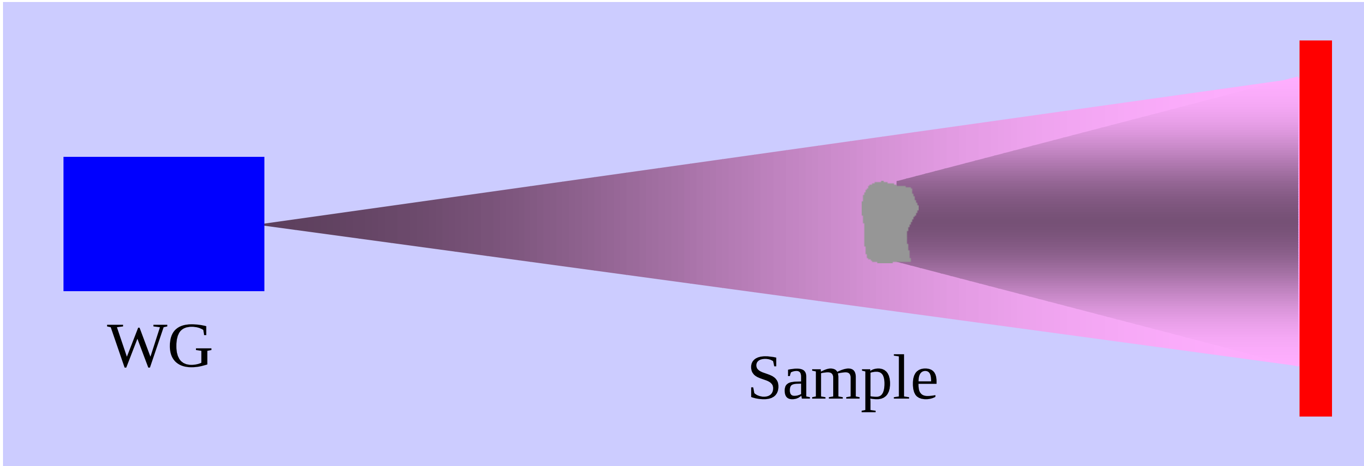


D_1 and D_2 serve to measure the initial and the delayed scattering pattern. Measurements of intensity fluctuation autocorrelation function are possible with fs temporal resolution.

Coherent scattering

First resonance order





High coherence volume and fs pulse duration

- Single shot measurements
- High spatial resolution

→ G. Campi

Conclusions

X-ray WGs as suitable optics for X-FEL:

• Spatial and temporal properties

• Beam splitting

Experimental schemes:

• Imaging

• Microscopy

•Coherent Scattering