

Report on the FEL optics activities

Damage investigations of FEL relevant optics

Hubertus Wabnitz and Kai Tiedtke

Outline

Motivation

**Measurement technique
and experimental set-up**

Former experimental results and modelling

Experimental campaign in November

Conclusion

Definition of damage

What can be regarded as damage?

Irreversible

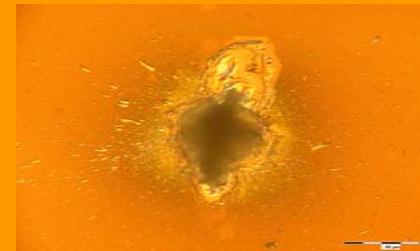
- **Single shot damage:** Ablation ...

- **Multishot damage:** *non-thermal*

near threshold damage, ageing...

thermal

fatigue



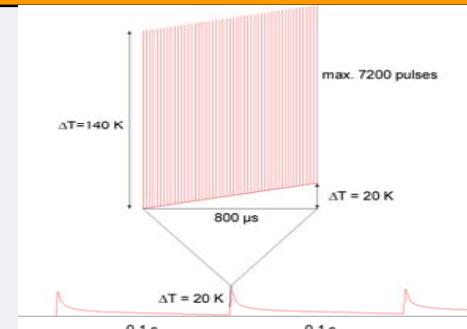
46nm amorphous C
on Silicon
at $\sim 10^{12} \text{ W/cm}^2$

Reversible

- **Multishot damage:** Thermal degradation of optics

no dissipation in between bunchtrains

In future



Why are we suspicious at all?

Trivial but true:

There is no experience with XFEL light sources yet
and there is a tremendous difference to synchrotrons!!

Parameter	Unit	SASE 1	SASE 2		SASE 3		
Photon energy	keV	12.4	12.4	3.1	3.1	0.8	0.25
Photons/pulse		10^{12}	10^{12}	1.6×10^{13}	1.6×10^{13}	1.0×10^{14}	3.7×10^{14}
Pulse energy	mJ	2	2	8	8	13	15
Pulse duration	fs	100	100	100	100	100	100
Photon beam divergence	μrad	1	0.84	3.4	3.4	11.4	18
Distance Undulator – Exp.hall	m	960	900	400	400	400	400
~ Beam diameter (FWHM) at exp. hall	mm	0.96	0.76	3.1	1.4	4.6	7.2
~ Intensity (unfocused)	W/cm ²	2.7×10^{12}	4.4×10^{12}	1.1×10^{12}	5.5×10^{12}	8.0×10^{11}	3.6×10^{11}

For comparison: At Doris ~ 10^6 W/cm² maximum

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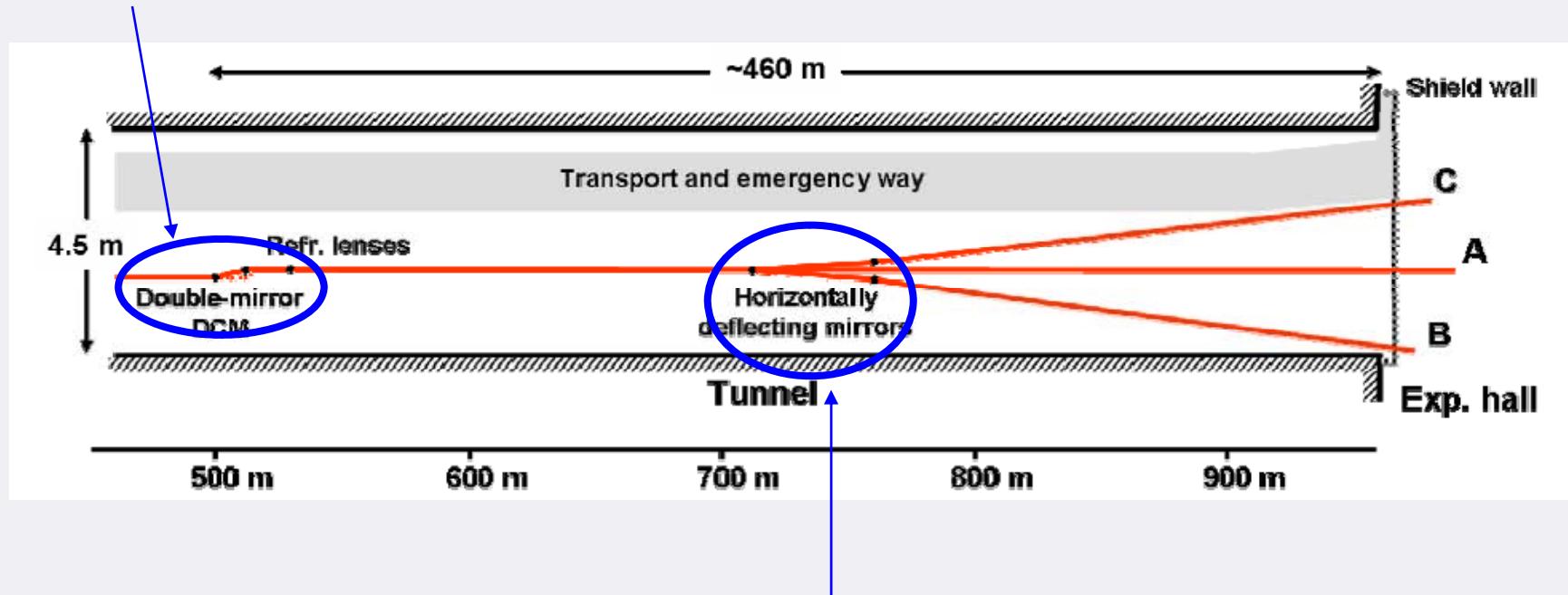
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For comparison: At Doris ~ 10^6 W/cm² maximum per pulse

Why do we need mirrors?

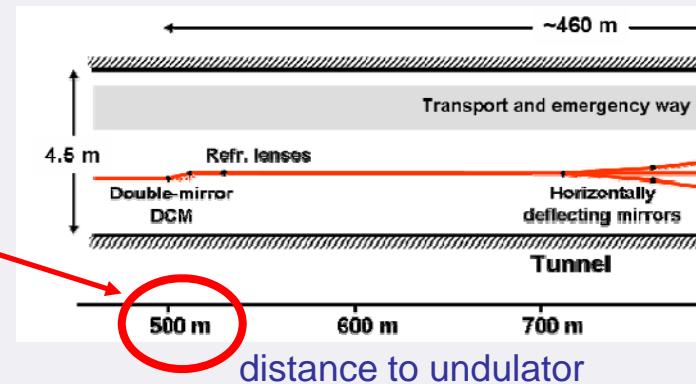
Safety reasons:

beam off-set hinders Bremstrahlung etc. to enter experimental area



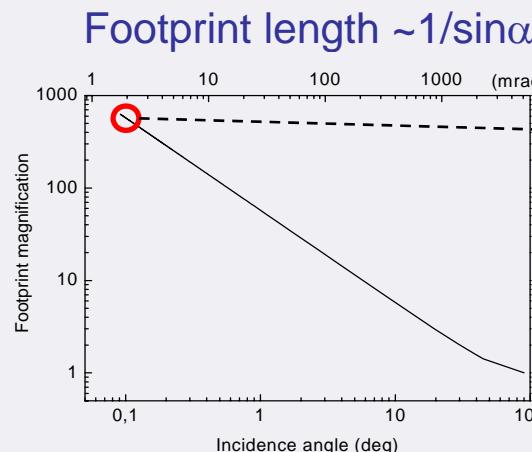
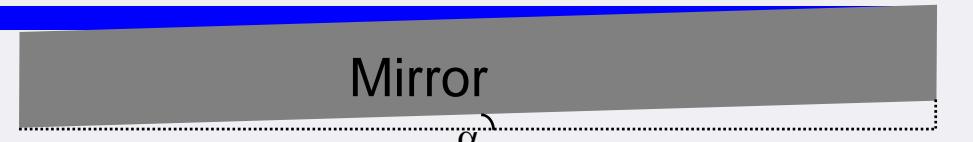
How to protect the mirrors?

Long distance
→ let photon beam diverge

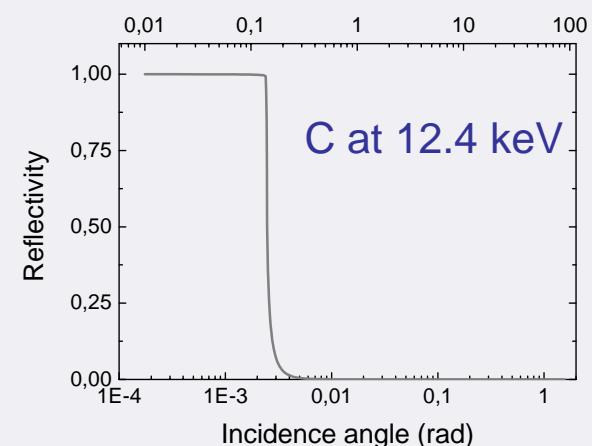


Gracing incidence angles
→ stretched footprint

photon beam



at 2 mrad
elongation of ~500
→ footprint's length
~0.7m (6σ at 12.4 keV)



Atomic dose model

$$D_A = E_{pulse} (1 - R) / A_{proj} l_{att} n_A$$

E_{pulse} : Energy per pulse

R : Reflectivity

A_{proj} : proj. beam footprint area

l_{att} : 1/e attenuation length

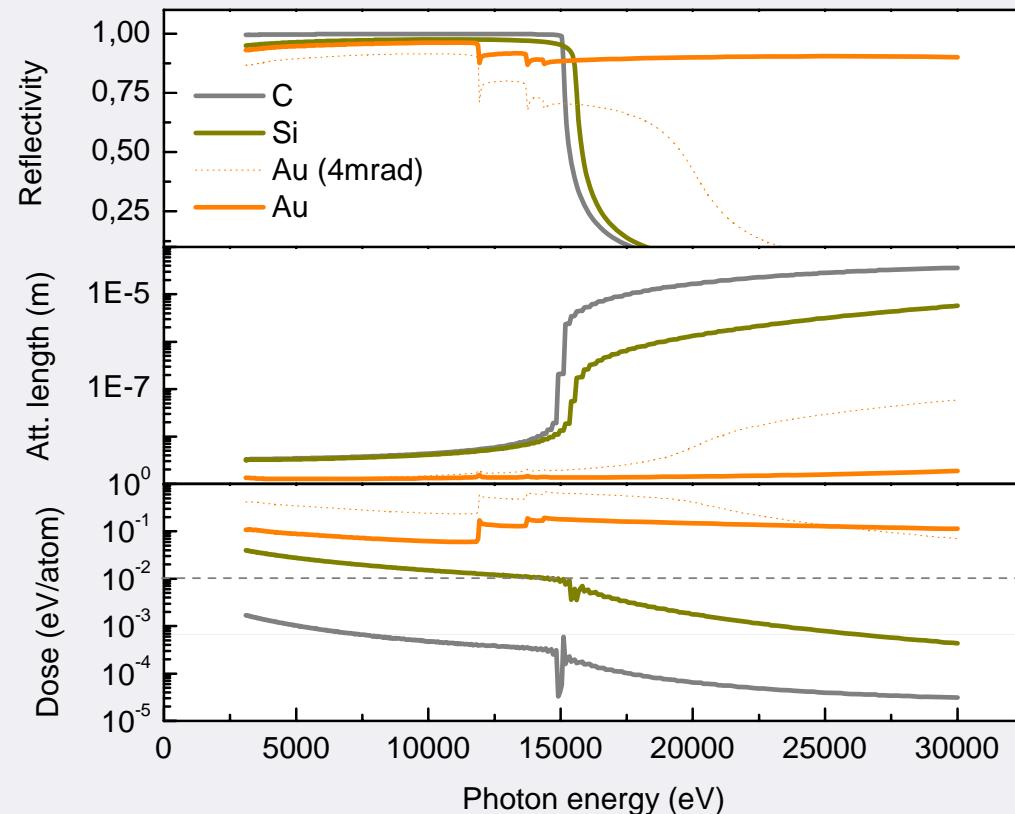
n_A : density of atoms

Implications

- low Z elements favour low dose
- dose of C coated mirrors always below 10meV/atom
- SASE 3 most critical (higher fluence=14mJ, $\alpha=10$ mrad)

SASE 1 and SASE 2 Double-mirror

$\alpha=2$ mrad



Benefits

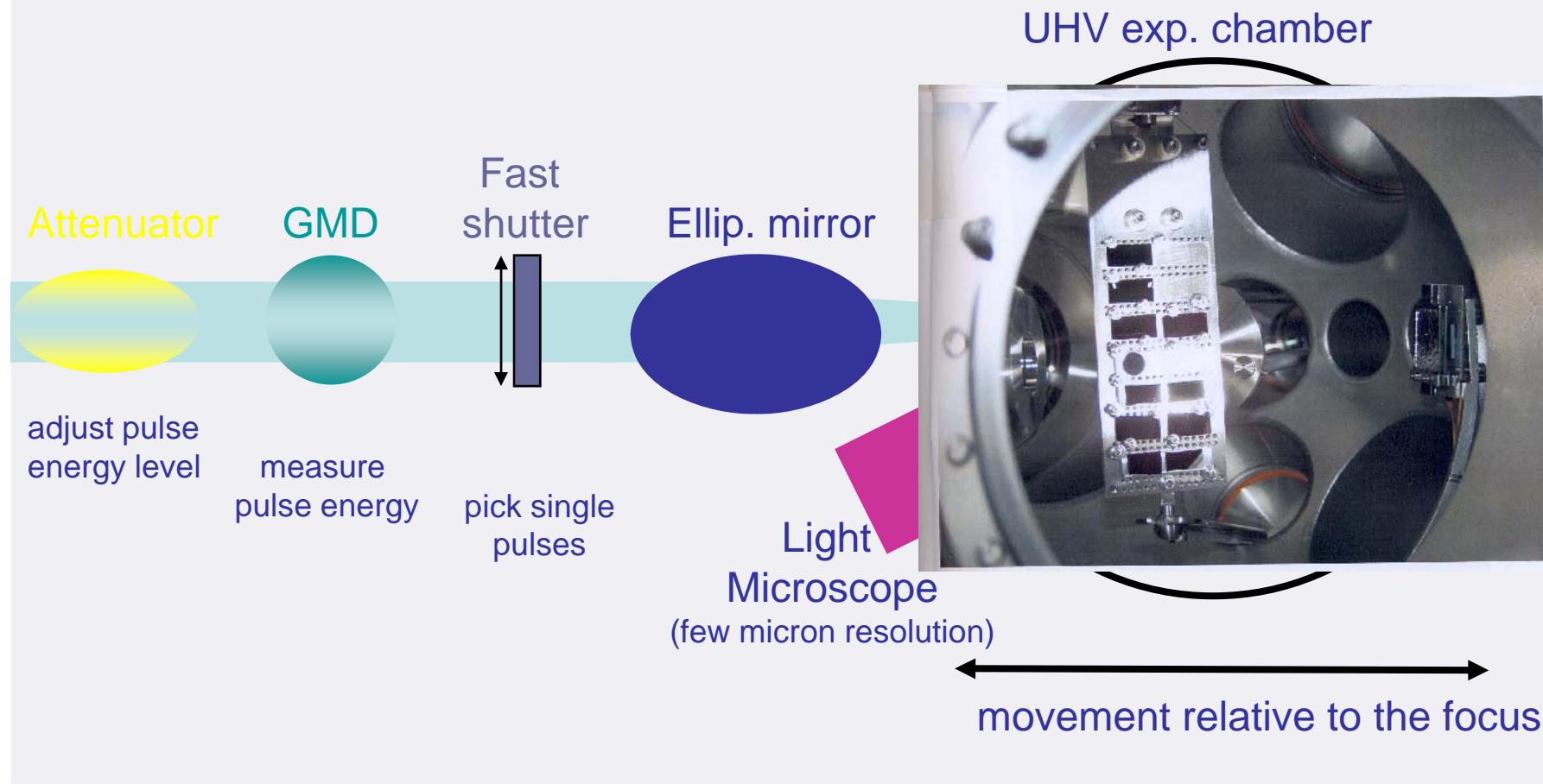


Enables reliable extrapolation to high photon energies
→ beam line optics can be ordered



Possibly higher deflection angles → might relax constraints on beamline optics
for upgrade (FLASH2, sFLASH)
Investigation of multi-layers → new optical schemes

Experimental setup (very principal sketch)

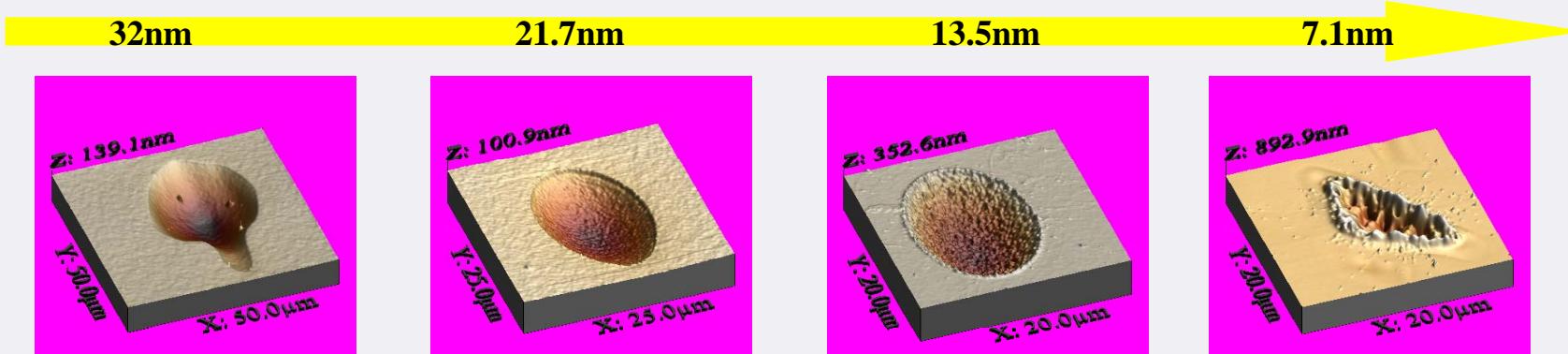


Examination methods

Light microscope for fast
but rough examination.

Post mortem examination

- AFM (morphology)
- Nomarsky (optical properties)
- Micro Raman (graphitisation...)



AFM pictures of PMMA for various wavelengths

Damage threshold

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Damage threshold of inorganic solids under free-electron-laser irradiation at 32.5 nm wavelength

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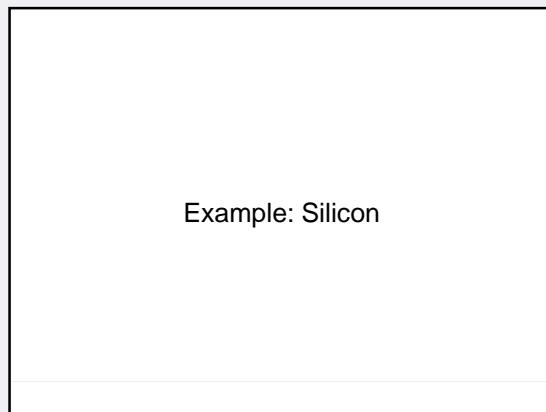
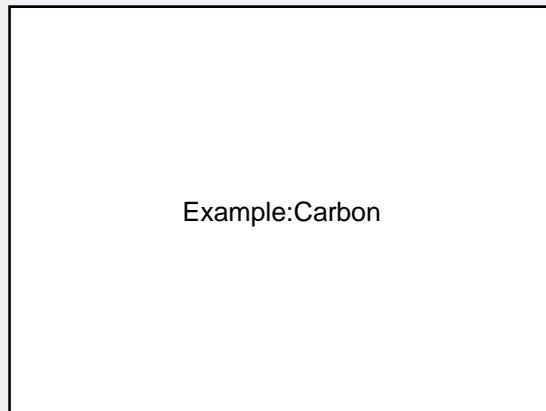
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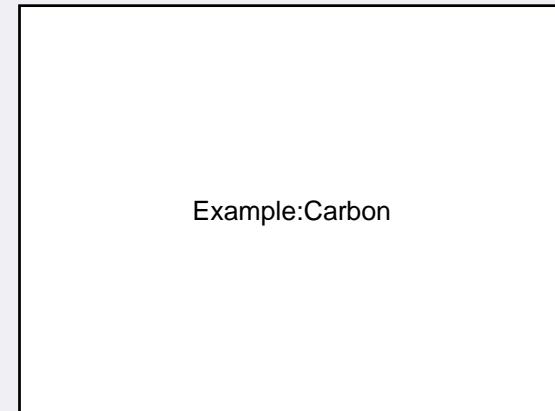
$\lambda = 32.5 \text{ nm}$	mJ/cm^2
Si	87 ± 45
a-C	65 ± 30
SiC	141 ± 70
B ₄ C	197 ± 100
CVD diamond	156 ± 75

Planned investigations for recent campaign

Extrapolation to shorter wavelengths



Grazing incidence measurements



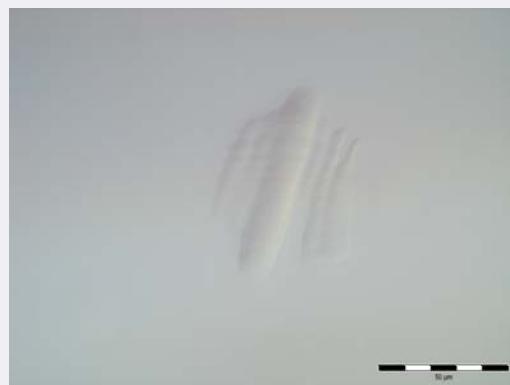
... and of course for a bunch of other materials

Recent beamtime

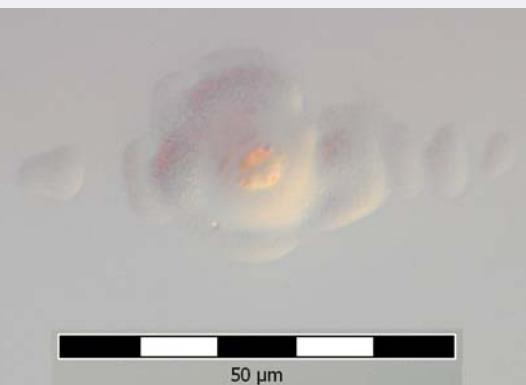
Beamline alignment

- | | |
|------------------------|--|
| 1st shift : 8h @7nm | → found unexpected imprints |
| 2nd shift: 12h @13.5nm | → beam characterisation, verified misalignment of beamline |
| 3rd shift: " | → „A very special FEL mode“ |
| 4th shift: " | → further beamline alignment, beam characterisation |
| 5th shift: " | → first data under reasonable conditions, but... |

Focal imprint in PMMA:
1st shift at 13.5nm
– misaligned beamline -



Focal imprint in PMMA:
3rd shift at 13.5nm
improved alignment



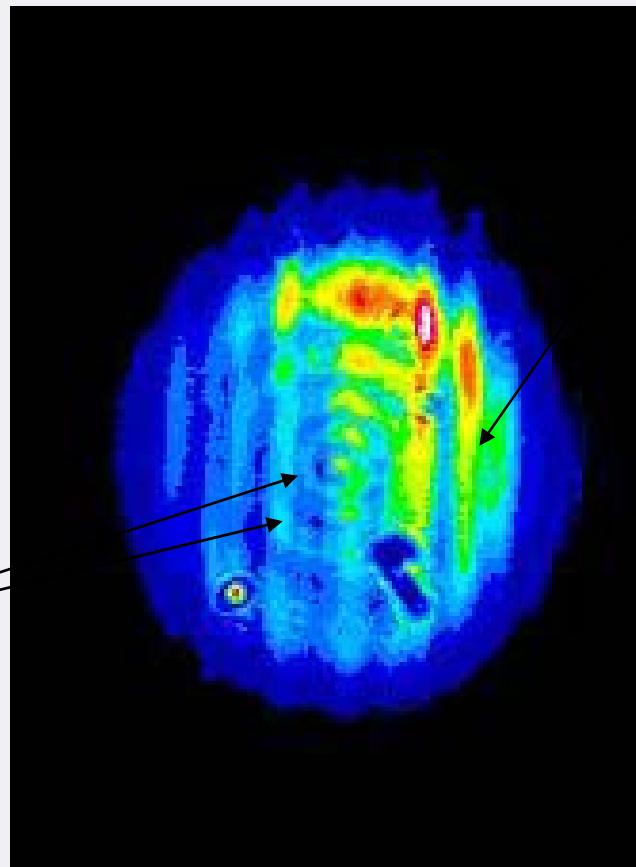
Beam shape

Image of photon beam

$\lambda=13.5\text{nm}$, 3mm-aperture

beam attenuated
with a $5\mu\text{m}$ thick Silicon foil
to protect CCD chip

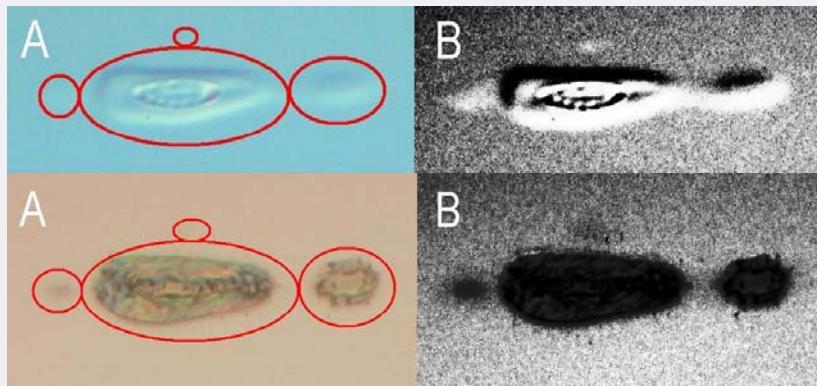
concentric feature expected
(diffraction at beam aperture)



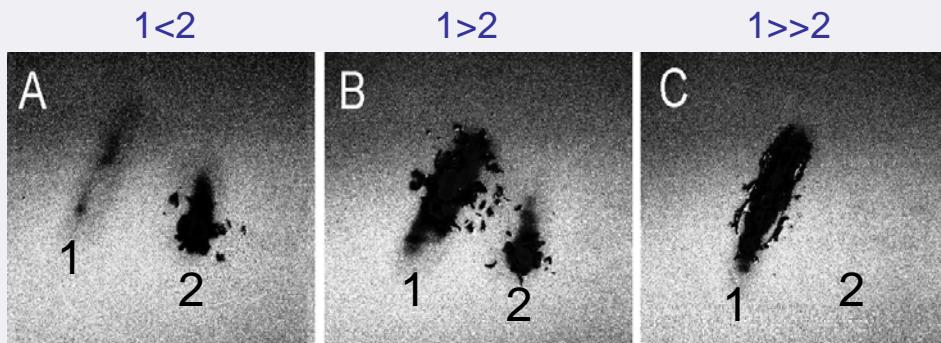
vertical feature is a bug
(diffraction at edge, somewhere)

Analysis

Multilayer samples



Got reasonable results (dam. thresholds...)
with „4 spot“ assumption
→ fulfilled only for stable beam conditions!!



„Flipping intensities“
→ unstable beam conditions

Conclusions

Successful:

- Data taking scheme and „shot to shot“ correlation
- Major input to beamline commissioning
- Estimation of damage thresholds for few materials

Painful:

- Spent 80% of beamtime for comissioning
- Largest part of measurement programme not accomplished

Thoughtful:

- For quantitative measurements
the commissioning time might be not appropriate

With contributions from

Collaborations

- Mirror coatings

Thin Film Technology GKSS-Geesthacht

- Experimental set-up

Institute of Physics, Warsaw

- Sample investigation (AFM...)

Institute of Physics/ASCR, Prague

- Metrology lab

BESSY,Berlin

- Multilayers

FOM-Institute for Plasma Physics, Rijnhuizen

- Mirror Manufacture

Zeiss

- Analysis and Modelling

Lawrence Livermore Lab

FEL facilities:

- **Daresbury Laboratory,Warrington**

- **Sincrotrone Trieste,Triest**

- **SPring-8,Hyogo**

- **LCLS**

Also participation in experimental campaign:
Sven Toleikis

Last but not least

**And
many thanks to you
for operating the machine**

The end