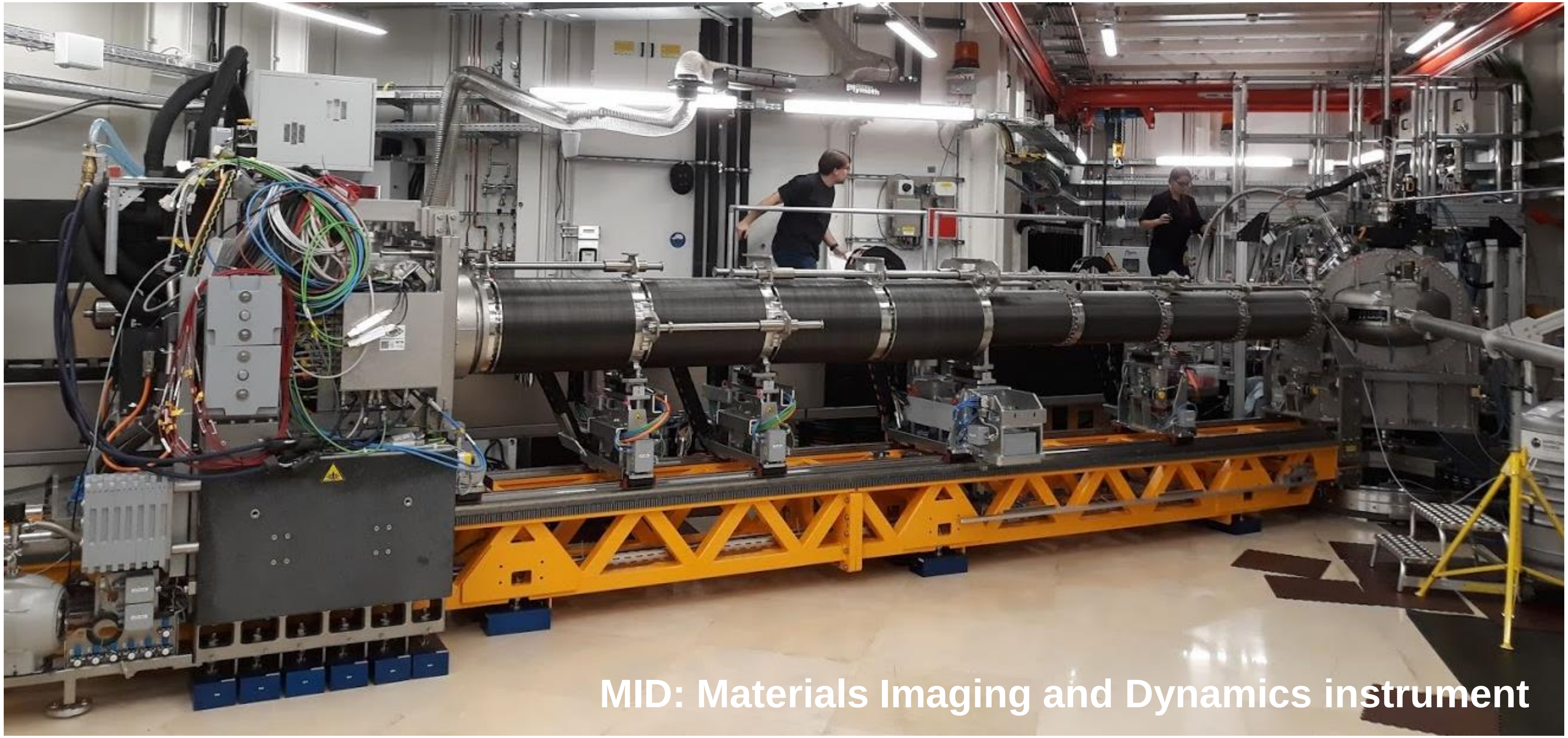
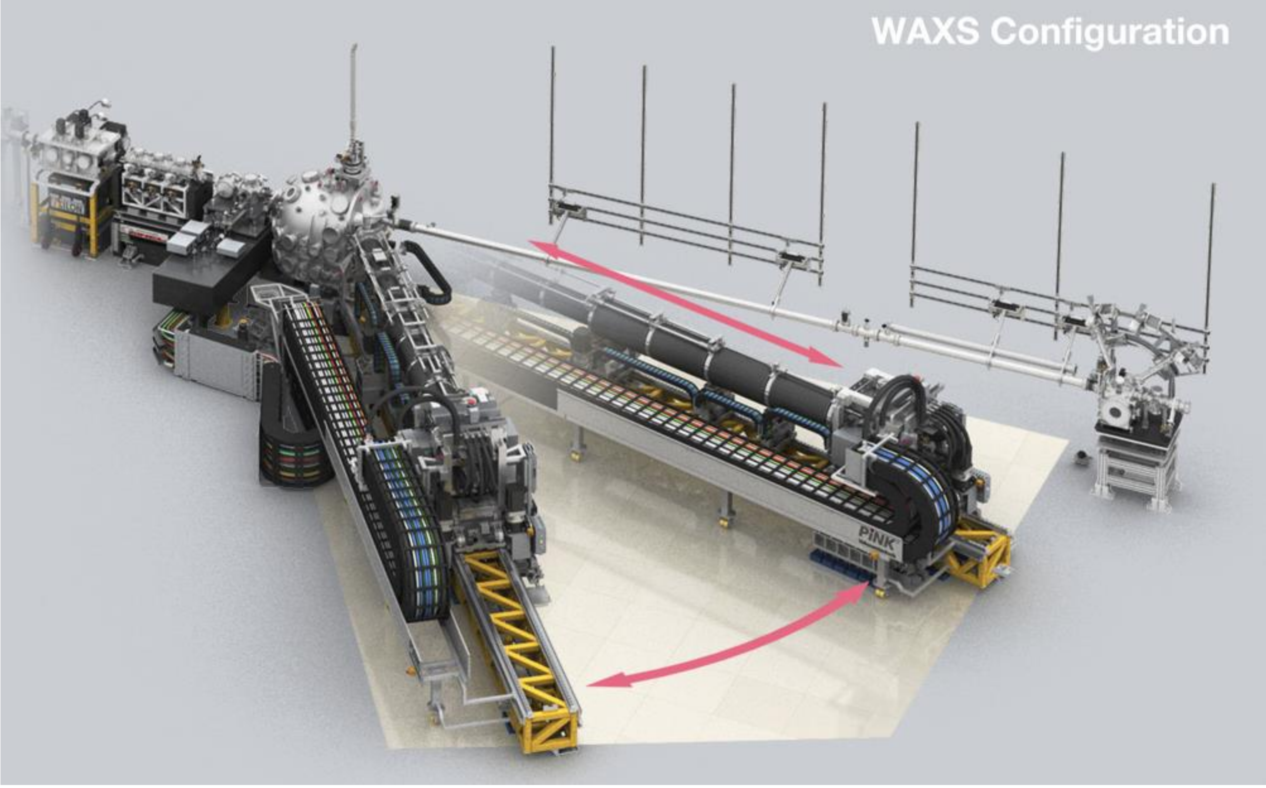
The case for self-seeded beams at MID



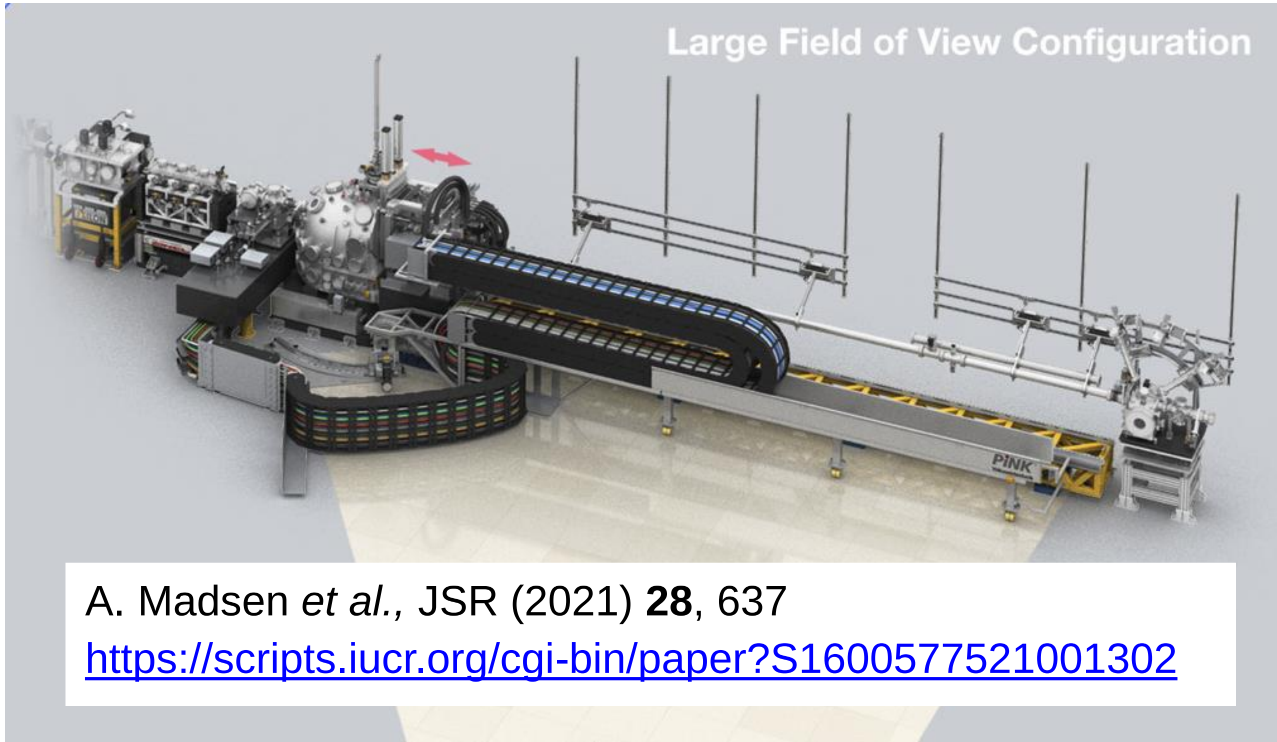
MID: Materials Imaging and Dynamics instrument

MID overview



MHz area detector, 10^6 pix of 200 μm size (AGIPD)
ePix, Gotthard detector, CCD cameras,…
Versatile setup, multi-purpose interaction chamber
Windowless (in-vacuum setup) or sample in air
Sample - detector dist: 0.2 m (LFOV) to 8 m (HiRes)
2θ up to ~50^o , 5 - 24 keV (7-18 keV used so far)

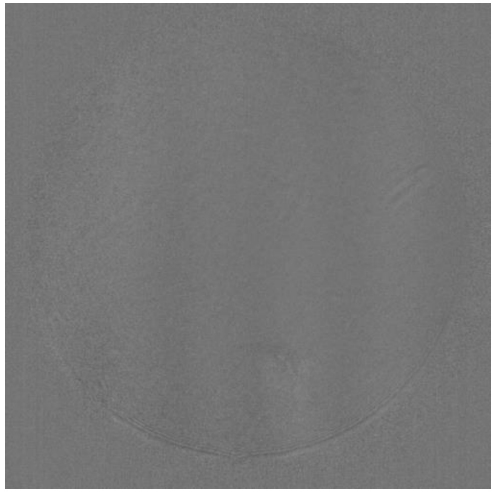
X-ray scattering and imaging: SAXS, WAXS, XPCS, phase contrast imaging and holography, CXDI, nano focusing, fs laser pump - X-ray probe



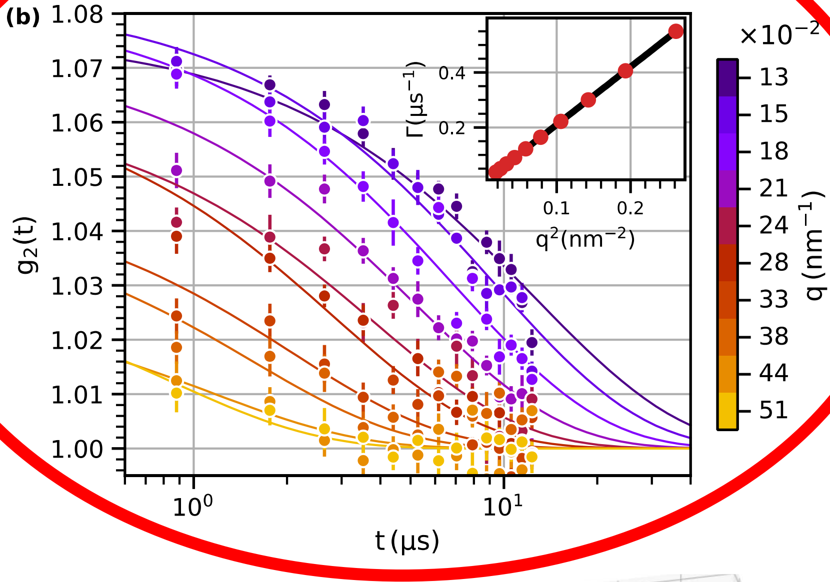
A. Madsen *et al.*, JSR (2021) **28**, 637
https://scripts.iucr.org/cgi-bin/paper?S1600577521001302

MID science

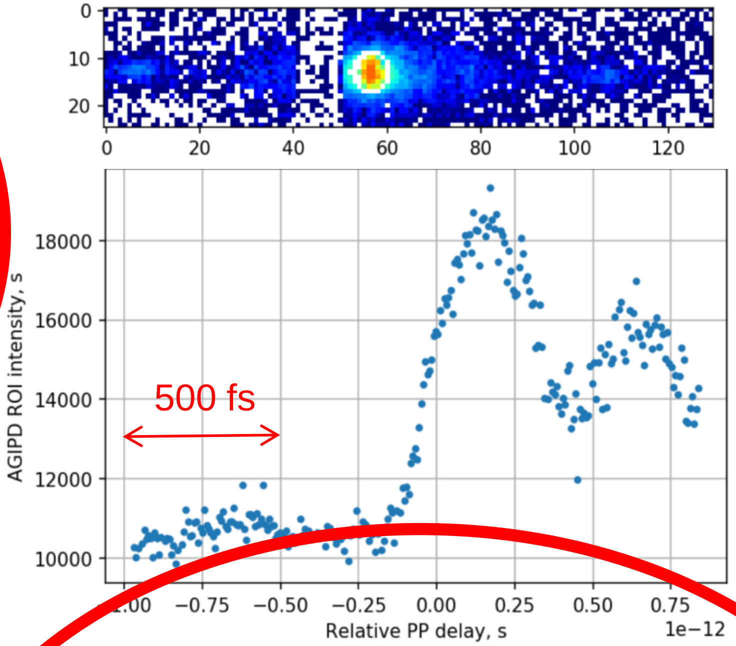
TR Imaging (holography)



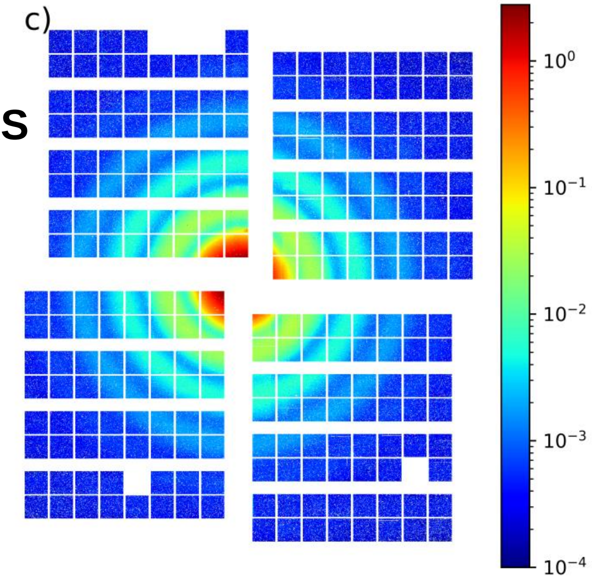
MHz XPCS



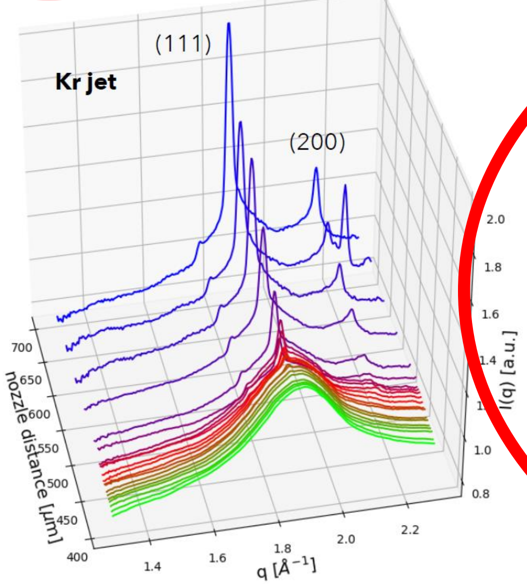
Laser pump – X-ray probe



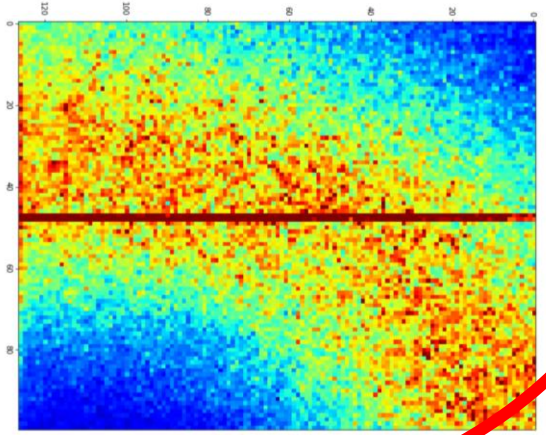
TR-SAXS



TR-WAXS



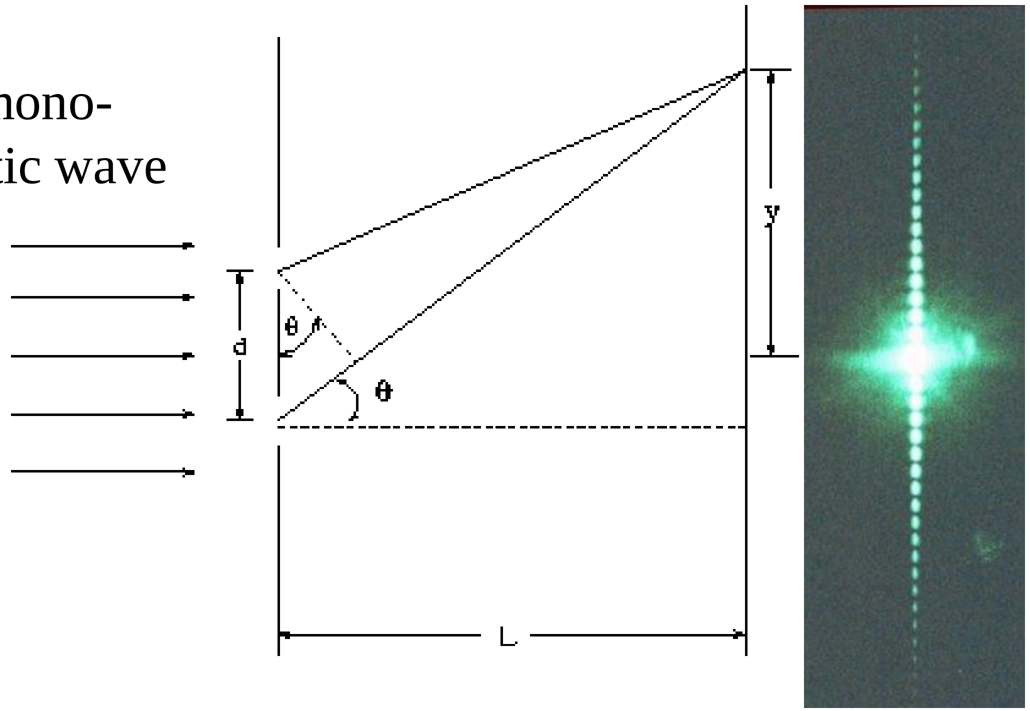
Coherent scattering and speckle



Beam coherence

Example: Young's double slit experiment (Thomas Young, 1801)
[wave-character of quantum mechanical particles (photons)]

Plane, mono-chromatic wave



$P=|\Sigma_j\Phi_j|^2$

Φ: probability amplitude

$\Phi_j \sim \exp[-i(\omega t-kl_j)]$

$\omega=ck,\ k=2\pi/\lambda,\ l_j(L,y)$

$P(y) \sim \cos^2(\pi yd/\lambda L)$

$\Delta y=\lambda L/d$

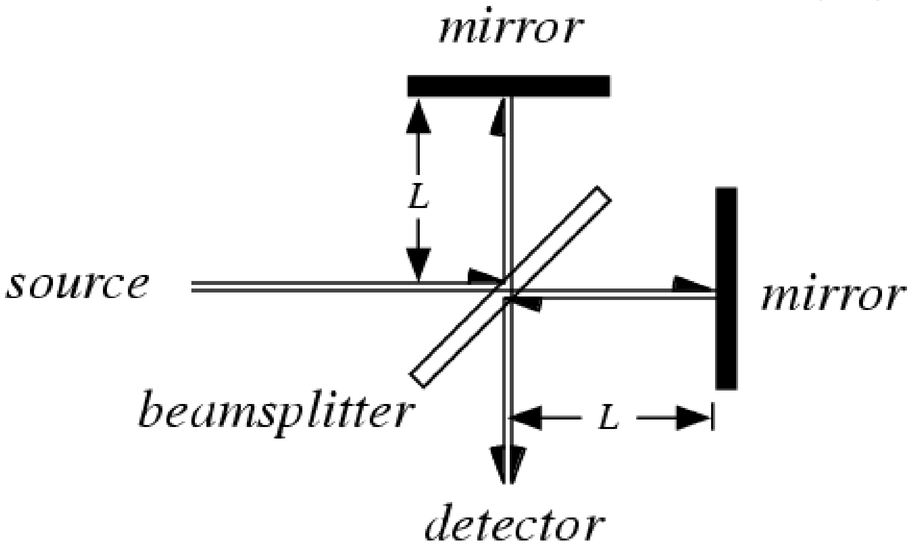
Thomas Young
(1773-1829)

Spatial coherence

Transverse coherence length

Beam coherence

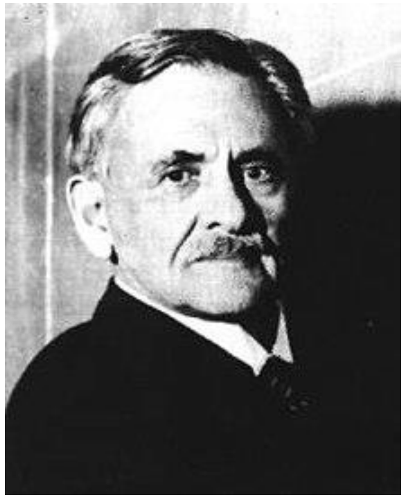
Michelson-Morley experiment (1887)



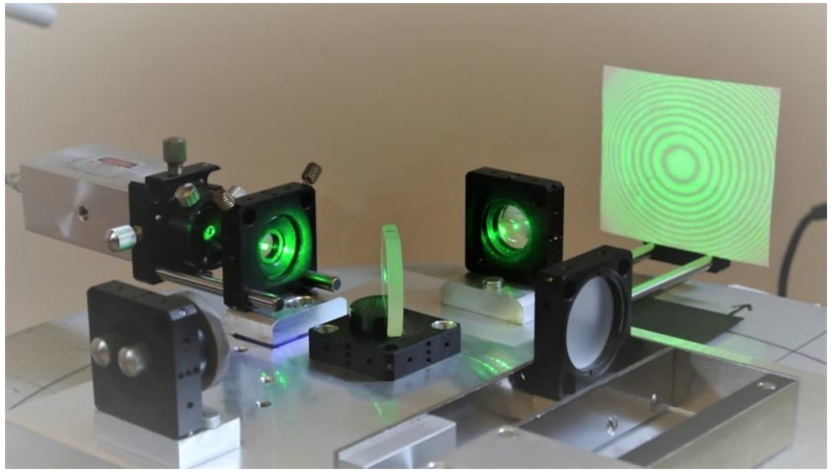
scienceworld.wolfram.com

The experiment failed but the Michelson interferometer is useful to demonstrate the longitudinal (temporal) coherence of light

Albert Michelson, 1852-1931



Edward Morley, 1838-1923

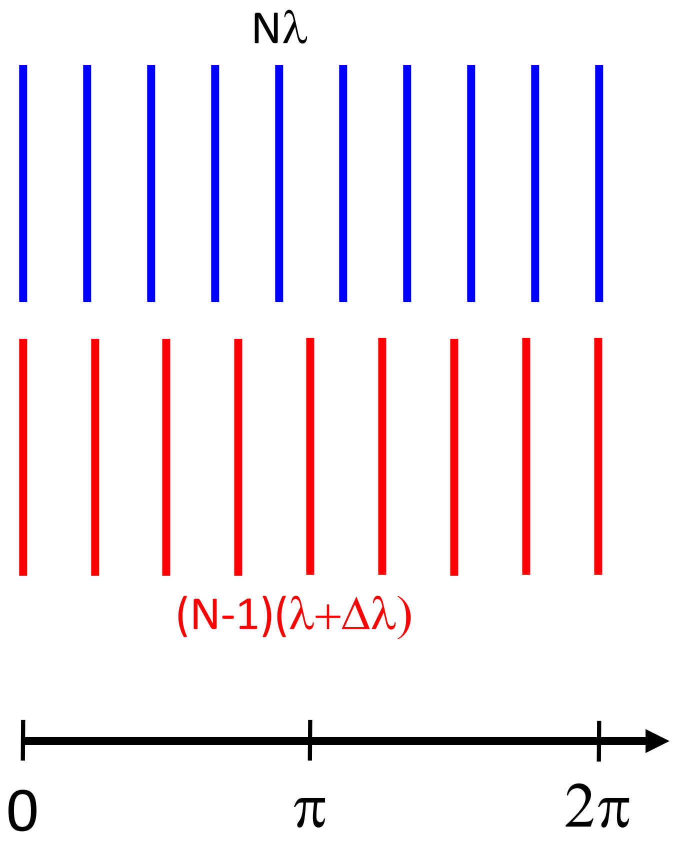


Courtesy Uni. Freiburg

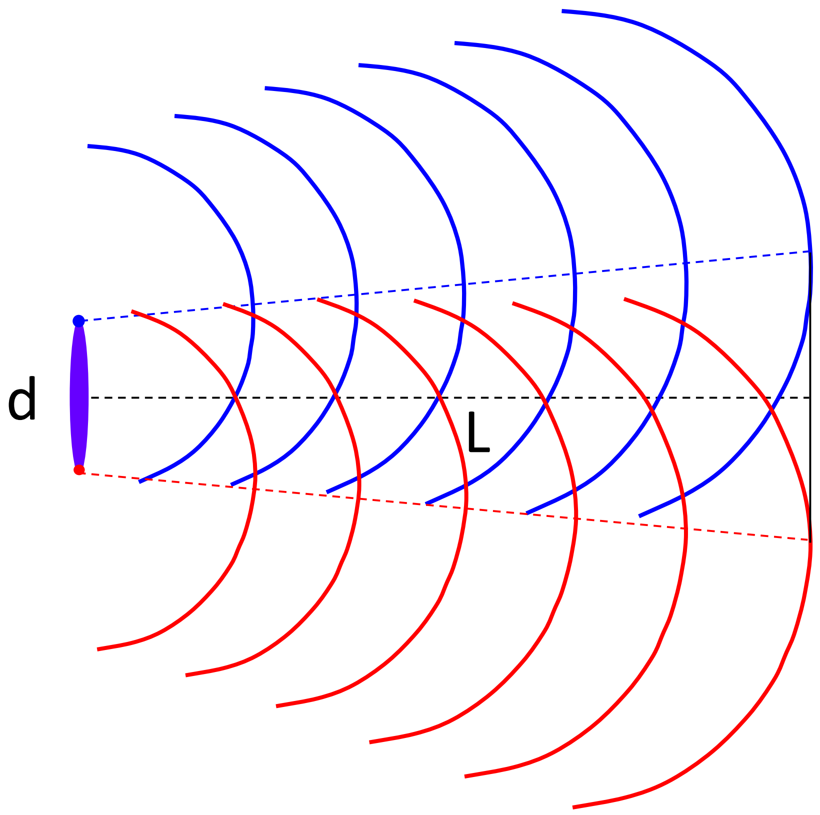
Longitudinal coherence length

$\boxed{\sim\lambda^2/2\Delta\lambda}$

Coherence length



Longitudinal coherence length $\boxed{\lambda^2/2\Delta\lambda}$

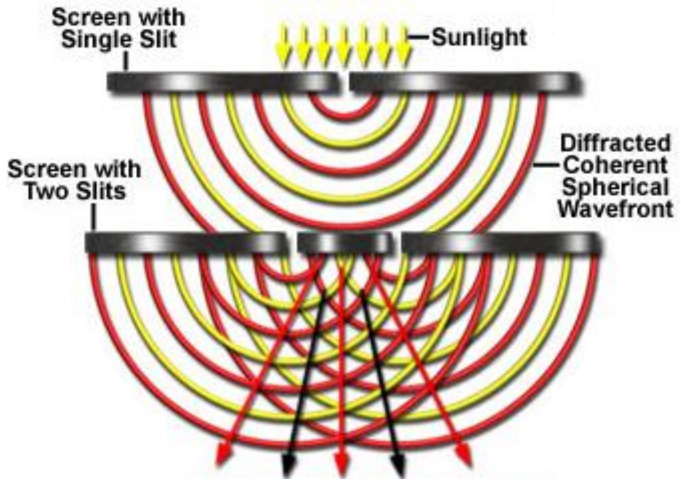


Transverse coherence length $\boxed{\lambda L/2d}$

Example of sunlight:

$$\lambda = 0.5\ \mu m$$
$$L = 1.5\ 10^8\ km$$
$$d = 1.4\ 10^6\ km$$

$$l_{h,v} = \lambda L/2d \approx 25\ \mu m$$



http://micro.magnet.fsu.edu/primer/java/interference/doubleslit/index.html

X-ray Coherence

Towards full spatial X-ray coherence

Novel MBA storage rings: beam size ~ transverse coherence length (h and v), up to several keV

XFELs: close to one transverse coherence mode

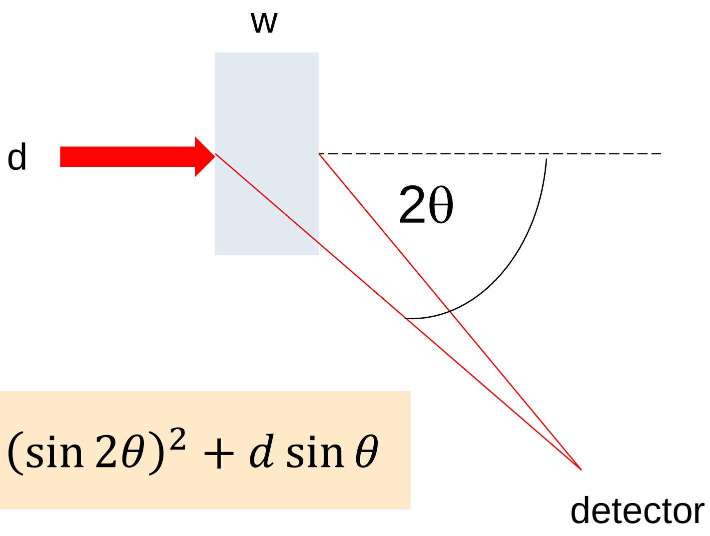
Longitudinal coherence (temporal coherence) is more difficult

All accelerator based X-ray sources need monochromators for wide-angle coherent scattering

Small beam size (d) and small sample thickness (w) also required in exp

$$\boxed{\lambda/(2\Delta\lambda/\lambda)}$$

Si reflection	$\Delta\lambda/\lambda$	long coh (12.4 keV)
(111)	1.4e-4 (1.7 eV)	0.4 um
(220)	6.1e-5 (0.8 eV)	0.8 um
(333)	1.1e-5 (0.1 eV)	4.5 um

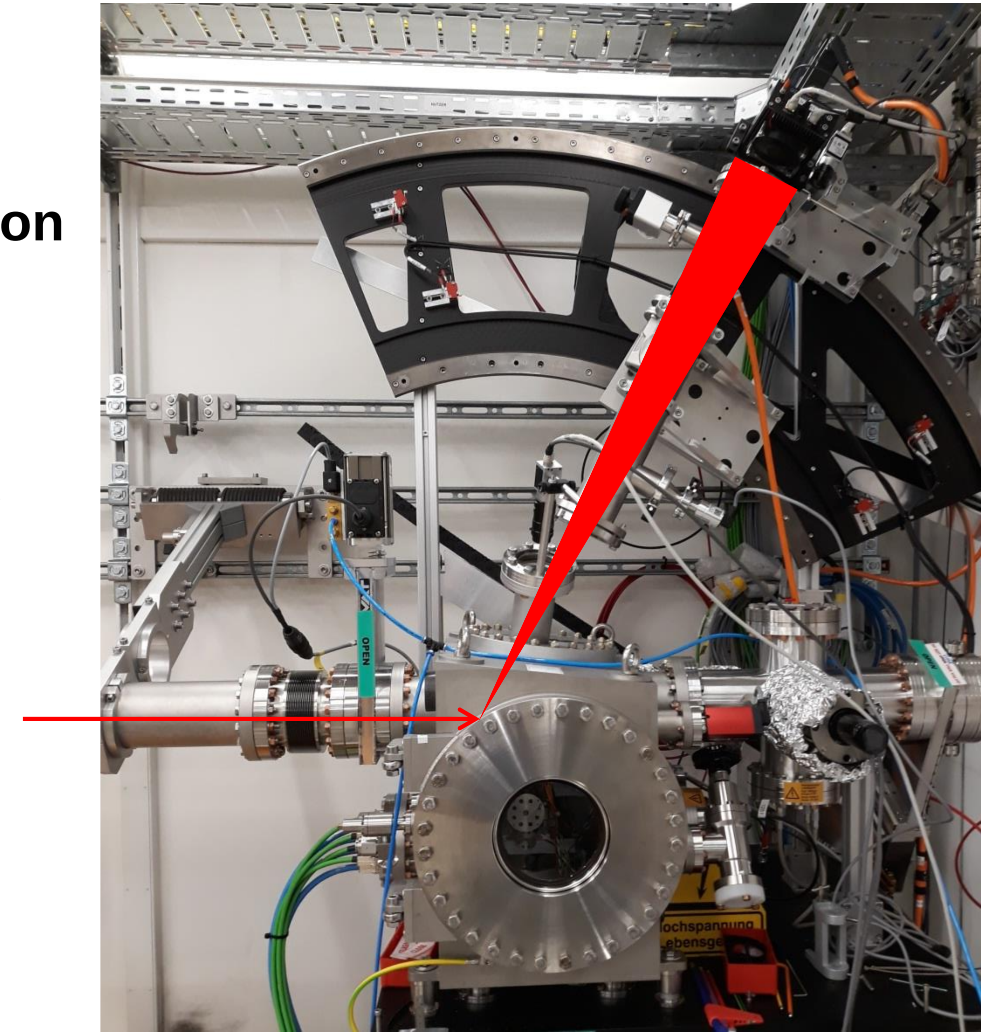


$$PLD \approx \frac{w}{2}(\sin 2\theta)^2 + d\sin\theta$$

Dispersive diamond spectrometer for single pulse spectra

DES:
Diagnostics End-Station

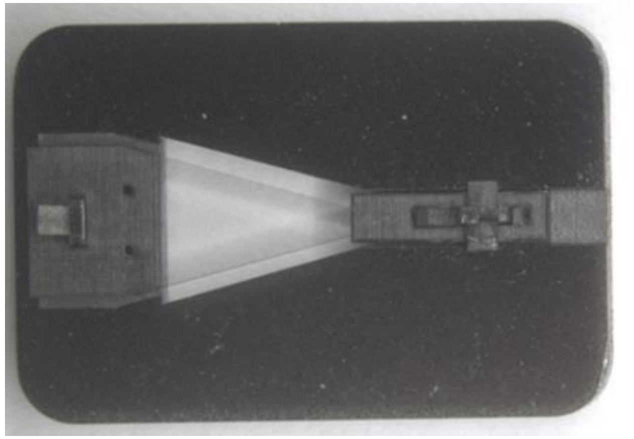
Spectral analysis,
pulse duration,
intensity, beam pointing



Dispersive spectrometer:
Gotthard 1d detector, 50 μm pix
500 kHz, 120 images/train

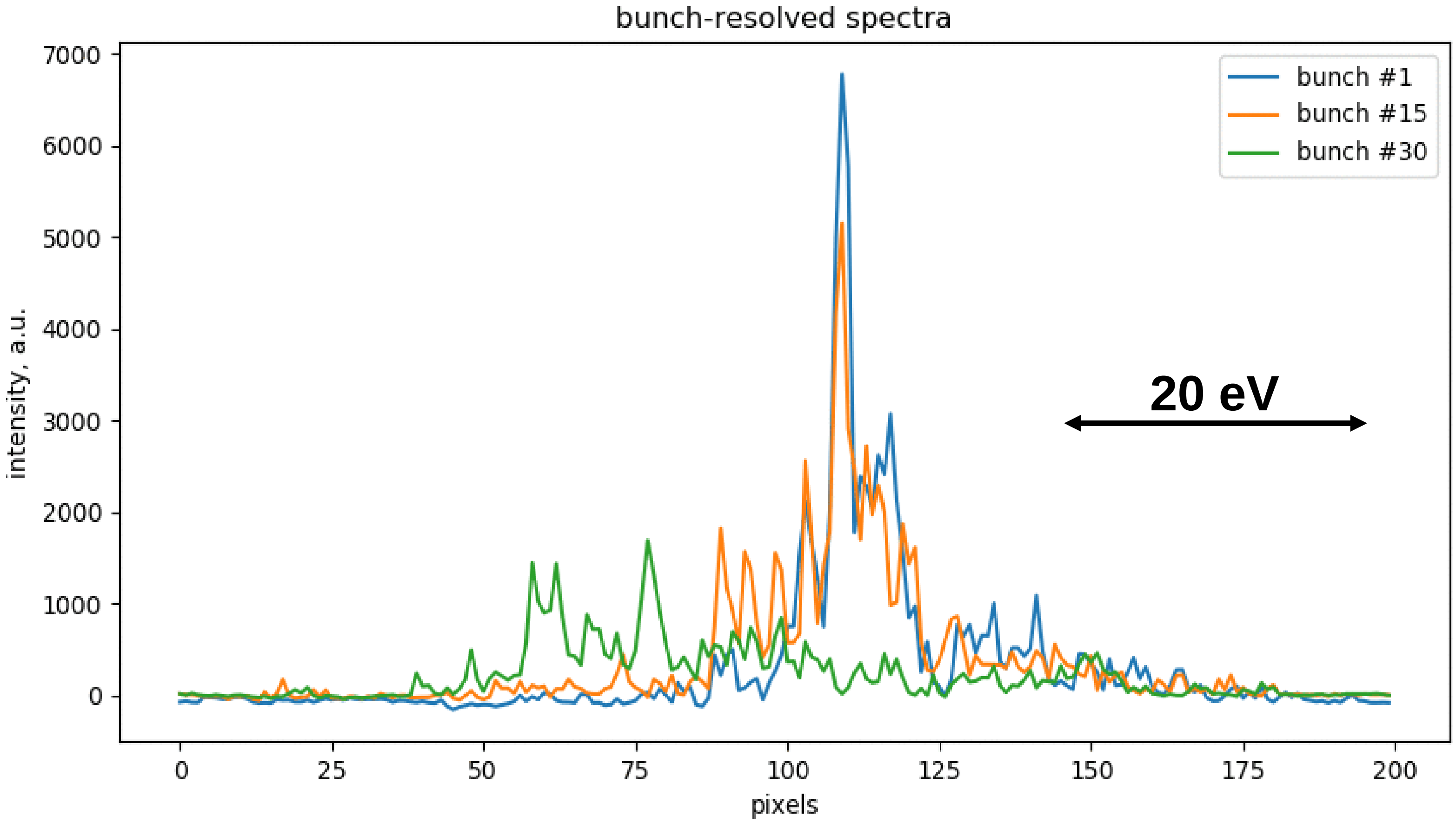
U. Boesenberg *et al.*
Optics Express **25**, 2852 (2017)

Dispersive diamond spectrometer for single pulse spectra



bent diamond crystal
R~ 10cm, C*(220)

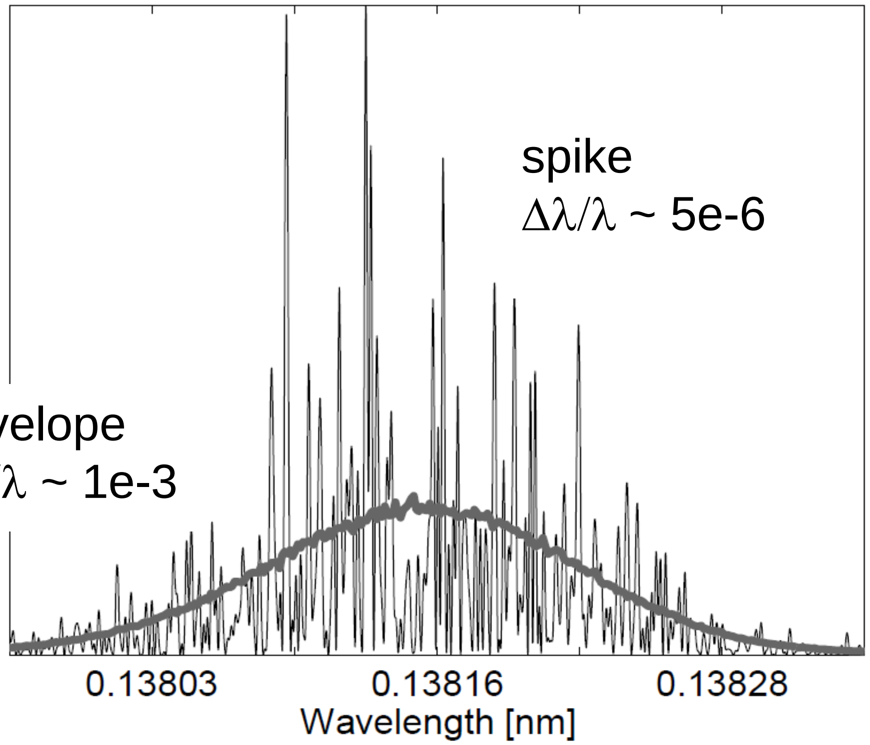
HPHT type IIa, 20 μm thick
made by TISNCM, Russia
(S. Terentev et al.)



Data from MID: 9.1 keV SASE, 30 pulses/train at 500 kHz, Gotthard detector at 1 m, resolution ~ 0.4 eV/pix.

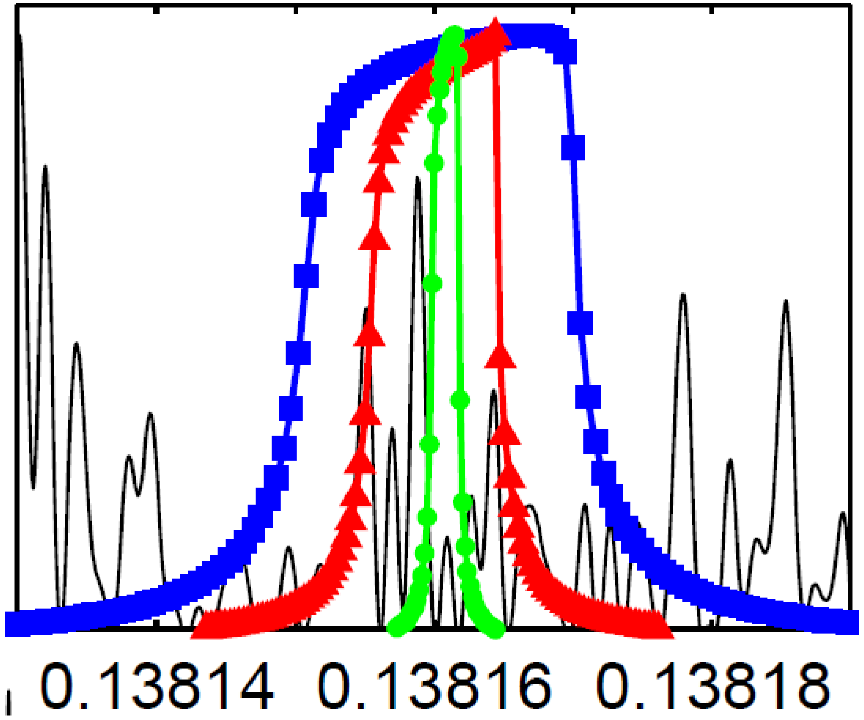
SASE beam + monochromator

Si(111) $\Delta\lambda/\lambda \sim 1.4\text{e-}4$
Si(220) $\Delta\lambda/\lambda \sim 6.1\text{e-}5$
Si(511) $\Delta\lambda/\lambda \sim 1.1\text{e-}5$



spike
$\Delta\lambda/\lambda \sim 5\text{e-}6$

envelope
$\Delta\lambda/\lambda \sim 1\text{e-}3$



About 15-20 spikes will pass through a Si(111) mono

Coherence time (and hence longitudinal coherence length) not well defined for Si(111) and Si(220)

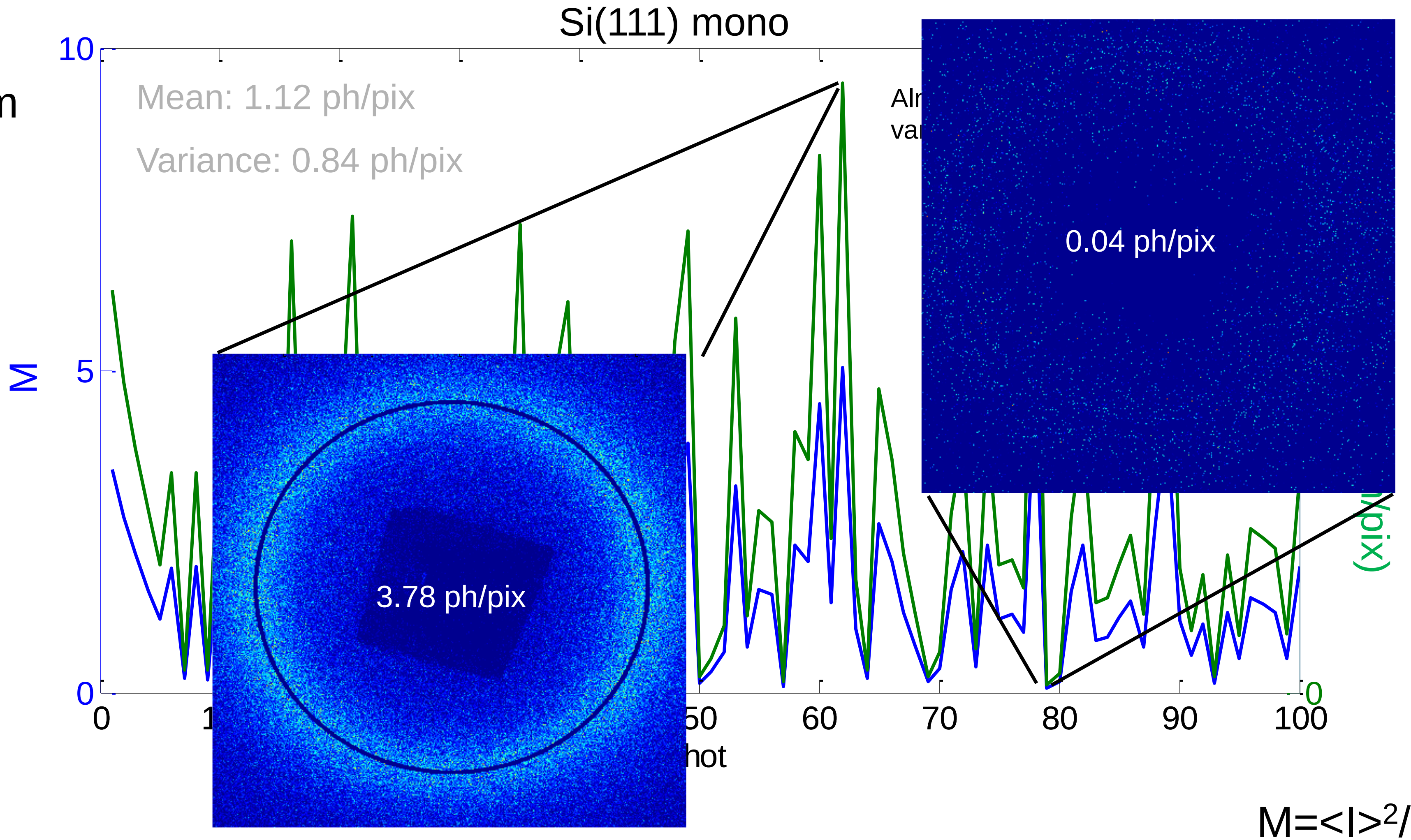
LCLS simulations, S. Lee *et al*., Optics Express **20**, 9790 (2012)

SASE beam + monochromator

Scattering from metallic glass

Data from
XCS @ LCLS
(120 Hz)

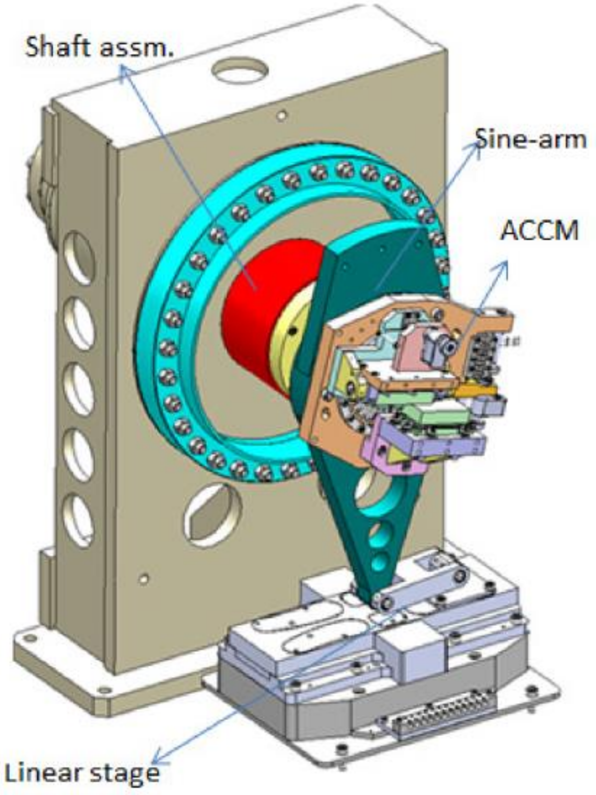
Amplification of SASE intensity fluctuations



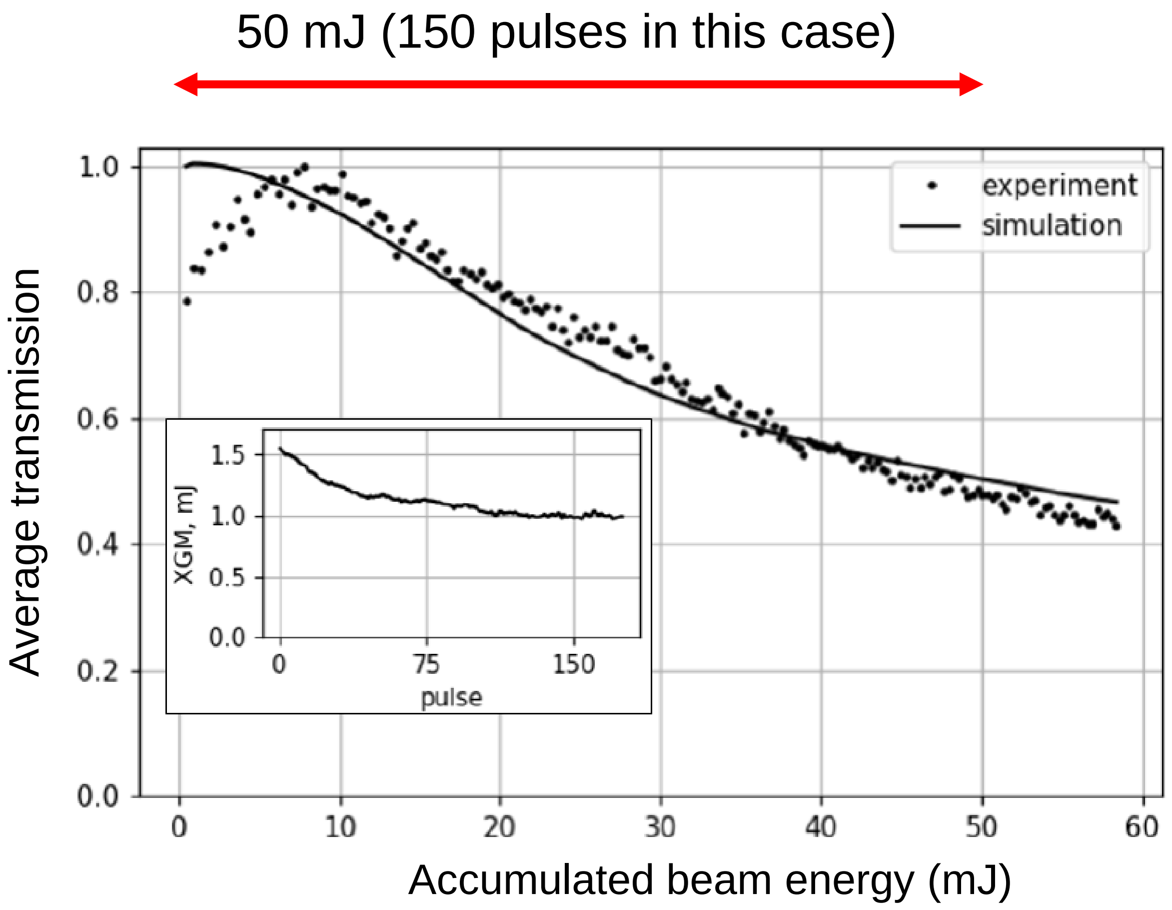
$M = \langle I \rangle^2 / \mathrm{Var}(I)$

MHz SASE beam + monochromator at MID

EuXFEL DCM design
Cryo-cooling, ACCM



X. Dong *et al.*, AIP Conf. Proc. 1741, 040027 (2016)



2.25 MHz, 0.5 x 0.5 mm (FWHM) beam size,
Si(111) reflection, crystal at 100 K

I. Petrov *et al.* (unpublished)

MHz HXRSS beam

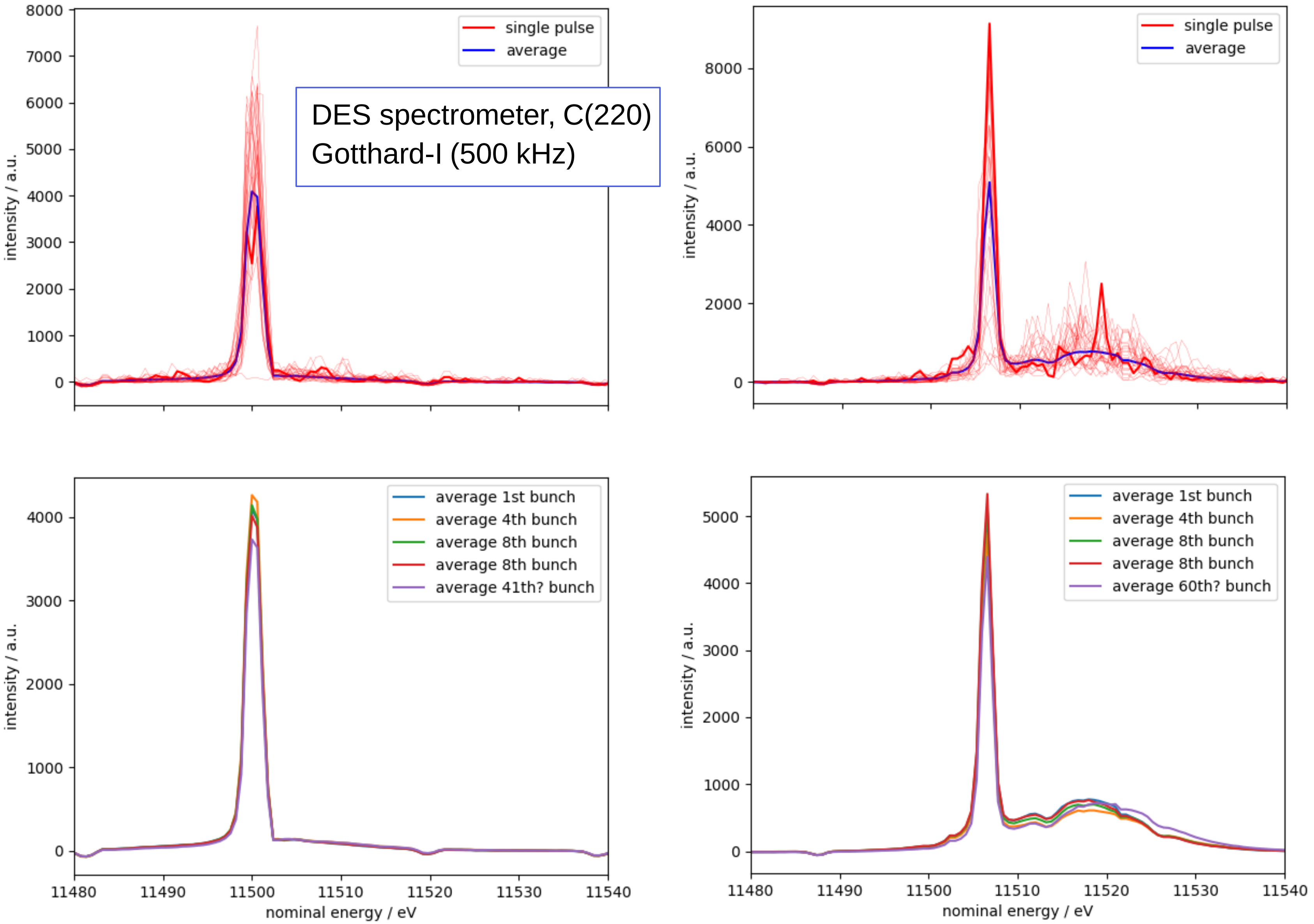
User exp 2595
Nov 2-7, 2021

2.25 MHz, 300 p/t
11.5 keV, ~0.6 mJ
1.2 eV (1e-4) BW (Av.)

Some fluctuations but very little taper over train

6-7 eV shift observed towards end but origin unclear

SASE bgnd increased



DES spectrometer, C(220)
Gotthard-I (500 kHz)

U. Boesenberg *et al.*

The case for self-seeded beams at MID

- 1e-4 – 1e-5 BW is required for many coherent scattering experiments
- Monochromators reduce intensity and increase intensity fluctuations
- Temporal coherence of reflected beam varies from pulse to pulse
- Cryocooled Si monochromators cannot transmit more than ~ 50 mJ during MHz train (adiabatic heating)
- HXRSS increases spectral brightness (Brilliance) → more coherent flux than SASE!
- HXRSS intensity fluctuates less and is more stable over train than beam from mono
- Need to better understand spectral drifts and origin (electrons, seeding xtals, spectrometer,…)

Thanks to the HXRSS commissioning team
and everyone involved in this project !