Title

Preliminary design of a set of four beamlines for the DLSR upgrade of the advanced light source

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U.S. DEPARTMENT OF ENERGY
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BERKELEY LAB

ALS-U
ADVANCED LIGHT SOURCE

Preliminary design of a set of four beamlines for the DLSR upgrade of the Advanced Light Source

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Diane Bryant, Arnaud Allézy, Grant Cutler, Valeriy Yashchuk,
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Simon Morton, Elaine diMasi, Howard Padmore

Lawrence Berkeley National Laboratory

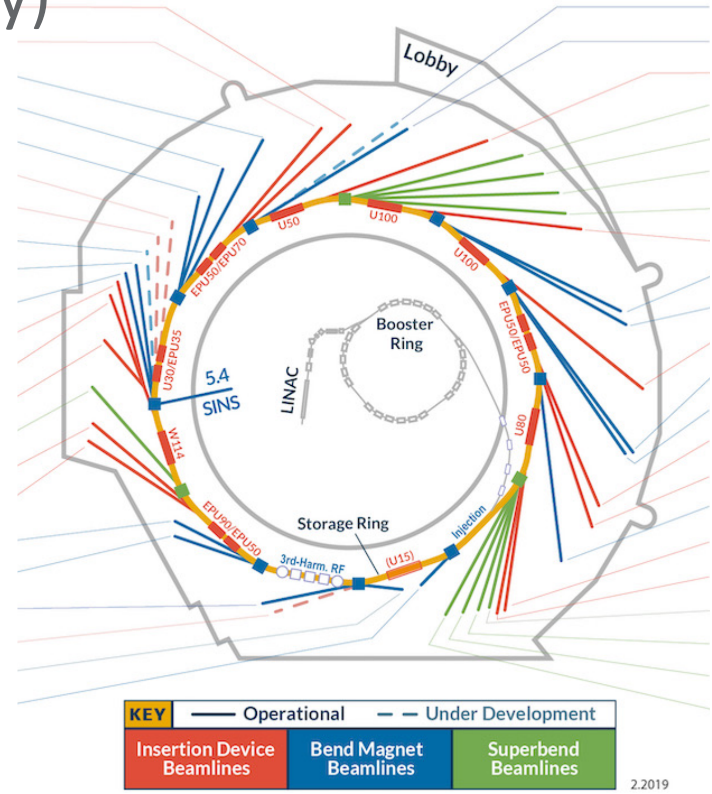
#11493-2

Advances in Computational Methods for X-Ray Optics V
SPIE Optics+Photonics 2020 (Virtual), August 25th, 2020

Upgrade of the Advanced Light Source

ALS-U: updating the ALS to a 4th generation Light Source

- DLSR upgrade of the storage ring
  - E = 2.0GeV (vs. 1.9GeV currently)
  - 9-bend achromat
  - Emittance: ε = 75 pm.rad (rms)
  - η = 1 coupling (round beam)
  - N_b = 284 bunches, I = 500mA
- 4 new beamlines
- Soft x-ray facility
- completion 2025



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Specification requirements for new beamlines

- Reuse existing facilities: the ALS
  - straight sections do not move
  - bend magnet beamlines move slightly
- New beamlines must fit on experimental floor (L=30m)
- Beam and energy resolution to match scientific needs
  - moderate energy resolution (more flux)
  - extreme power density on the sample

Four new and upgraded beamlines

4 beamlines and 7 branches

- **FLEXON**
  - Branch 1: scattering 400—1400 eV, >5000:1 RP, 15 µm focus,
  - Branch 2: in development
- **Tender**
  - Branch 1: imaging, 2—8 keV, >5000:1 RP, <3 µm focus
  - Branch 2: scattering, 1—5 keV, >5000:1 RP, <3 µm focus
- **COSMIC**
  - imaging, 250—2500 eV, >5000:1 RP, 12µm focus size
- **MAESTRO**
  - Branch 1: µARPES 60—600 eV, >15000:1 RP, 10 µm focus size
  - Branch 2: nano-ARPES 60—600 eV, >15000:1 RP, 10 µm focus size

Coherence

filament beam size and divergence

$\sigma_p=(2\lambda L_u)^{1/2}/2\pi$

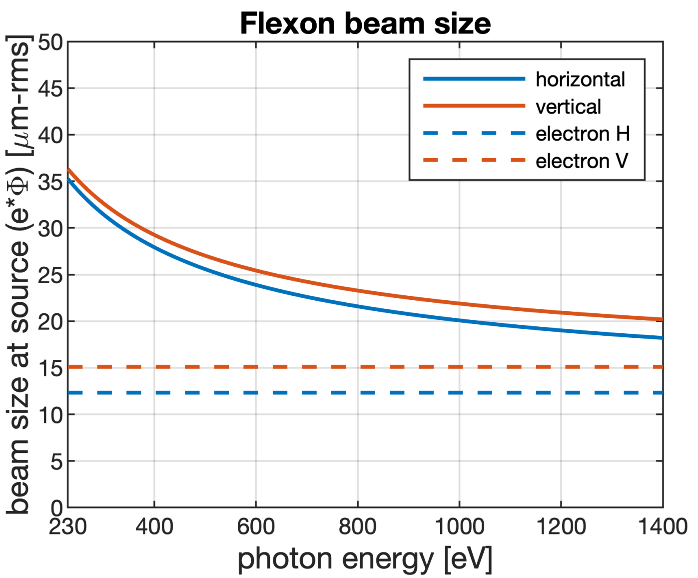
$\sigma_p'=(\lambda/2L_u)^{1/2}$

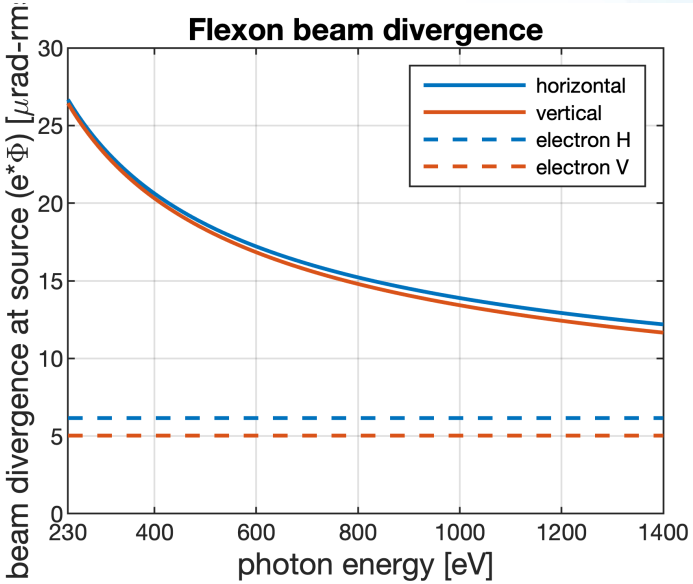
- Very high coherent fraction for soft x-ray operation (>50%)

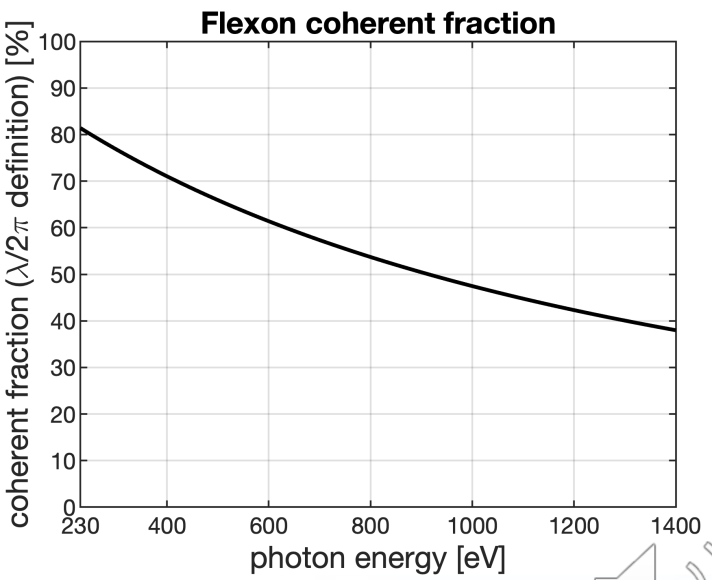
$\Sigma = (\sigma_p^2+\sigma_e^2)^{1/2}$

$\Sigma' = (\sigma_p'^2+\sigma_e'^2)^{1/2}$

c.f. $=\Sigma/\sigma_p$



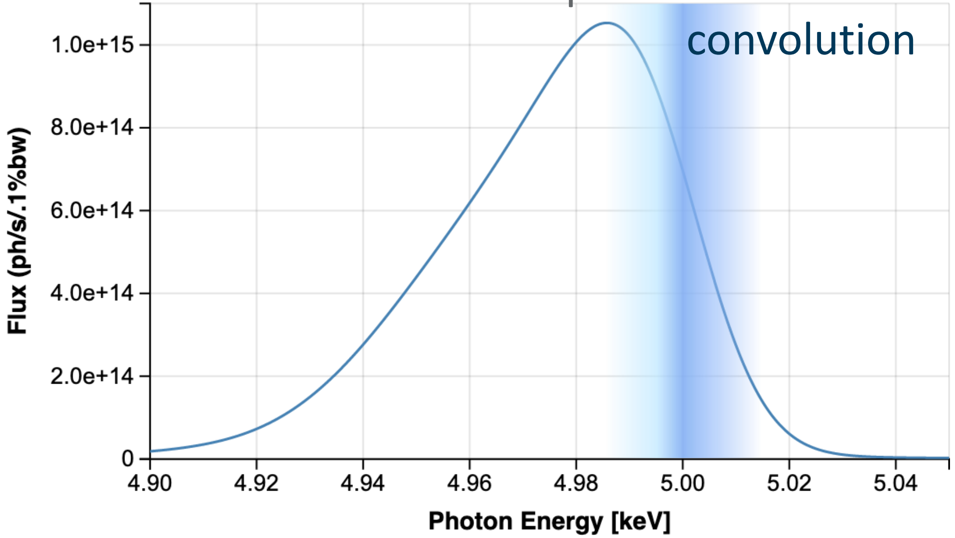


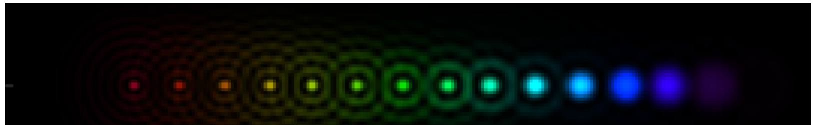


Coherence in the upper part of the spectrum

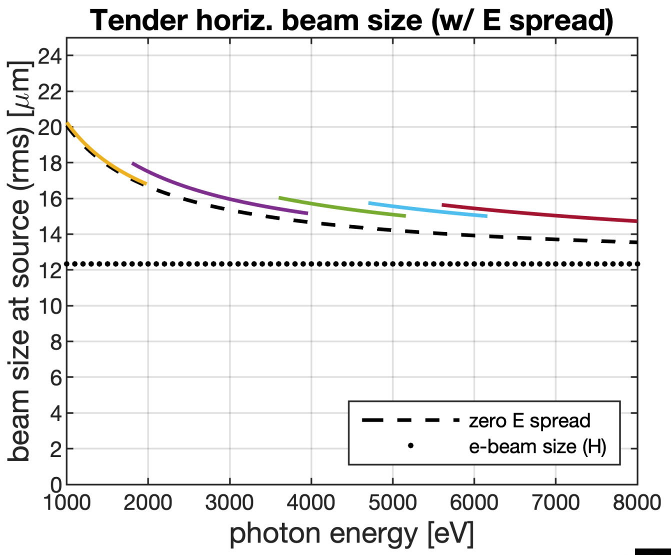
At higher harmonics, the effect of the energy spread in the electron beam can dominate the photon beam emittance, but still a good coherent fraction at higher energy

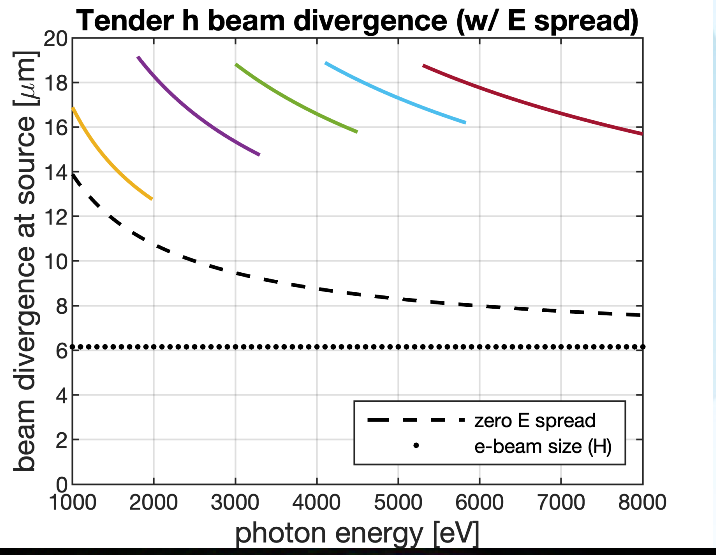
simulations with sirepo.com

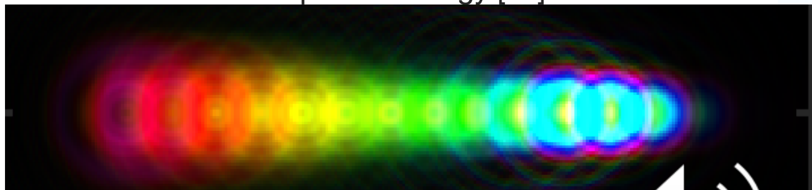




beam shape near resonance at focus







beam shape near resonance out of focus (1m)

Undulator radiation brightness and coherence near the diffraction limit
Richard P. Walker doi.org/10.1103/PhysRevAccelBeams.22.050704
Physical Review Accelerators And Beams 22, 050704 (2019)

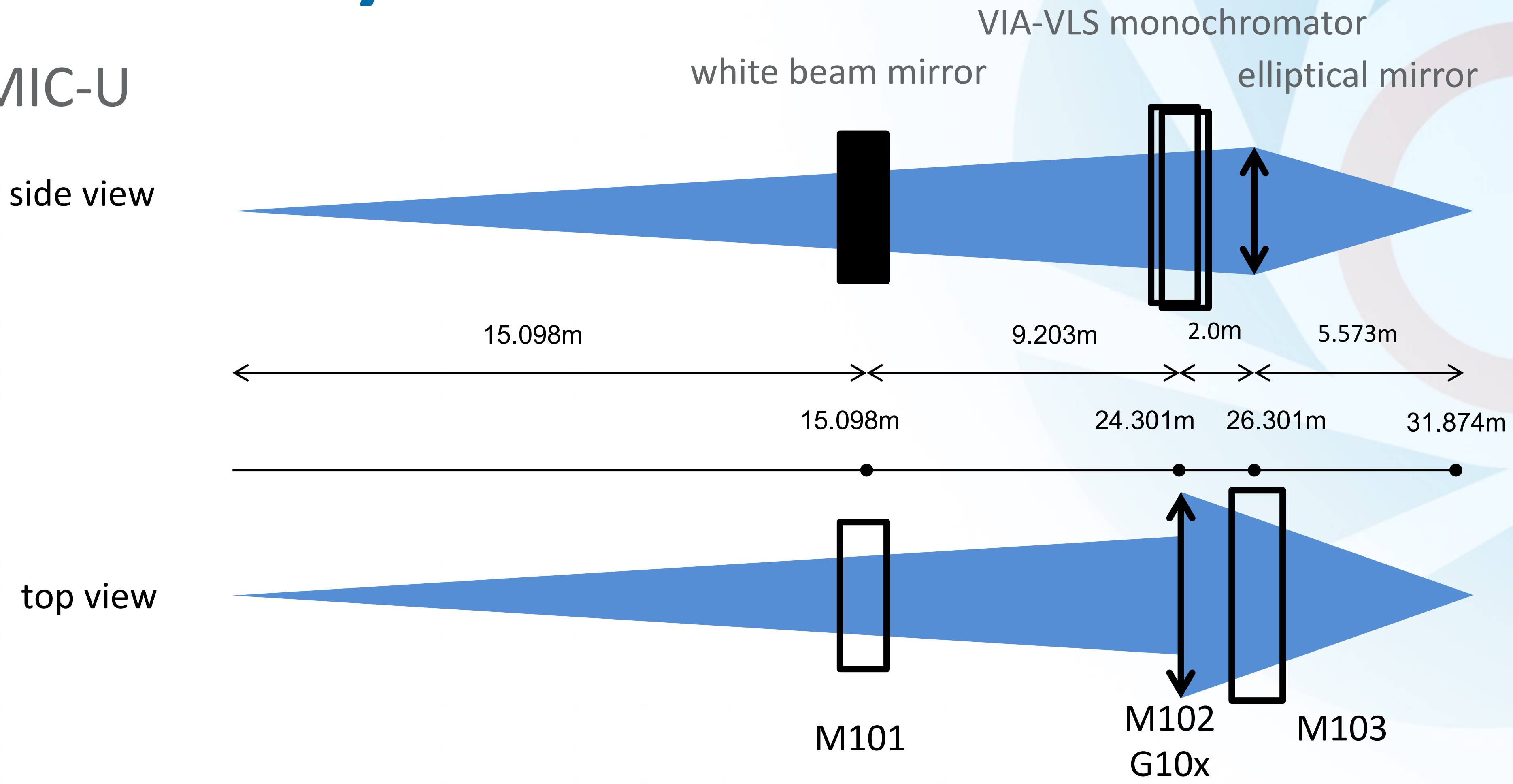
Beamline design

Diffraction-limited performances:

- Minimal number of optics (2H+2V)
  - avoid mirror figure error
  - avoid vibration
- Keep beam round
- Adjustability
  - Vertical beam adjustment: VIA-VLS monochromator
  - Horizontal beam adjustment : Adaptive Optics

Beamline layout

COSMIC-U



horizontal demagnification: $1/M_h = p_h/q_h$

vertical demagnification: $1/M_v = \mathbf{c} \cdot p_v/q_v$

Soft x-ray beamlines

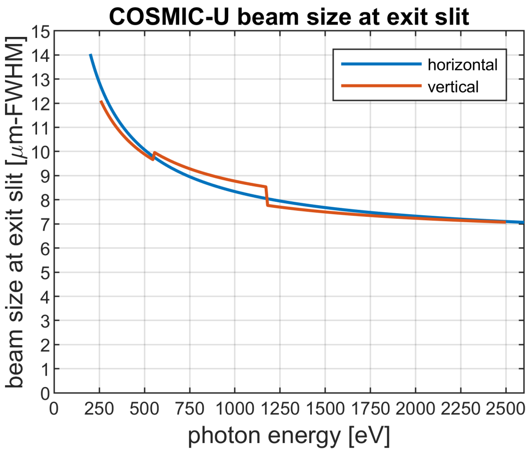
- VIA-VLS grating monochromator
  - dispersion and focusing
  - for flexibility, heatload compensation
- Round beam:
  - matching of the H and V demagnification

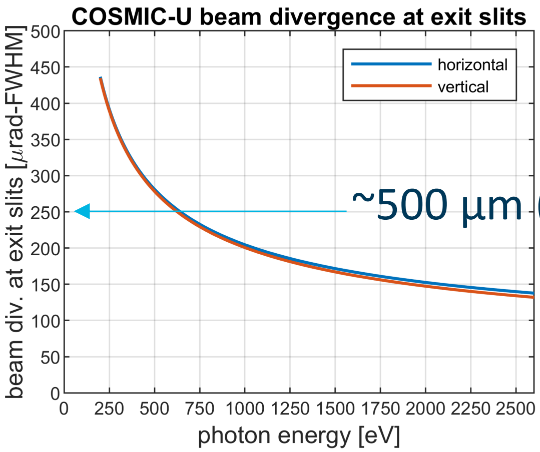
resolving power ≈ $p \cdot \sqrt{g_0(c^2-1)/L_u} \cdot \pi/(2 \cdot 2.35)$

demag = $c \cdot p/q$

light efficiency $1/c$

W. Jark J.Synchrotron Rad. (2019) 26, 1181
doi.org/10.1107/S1600577519004120





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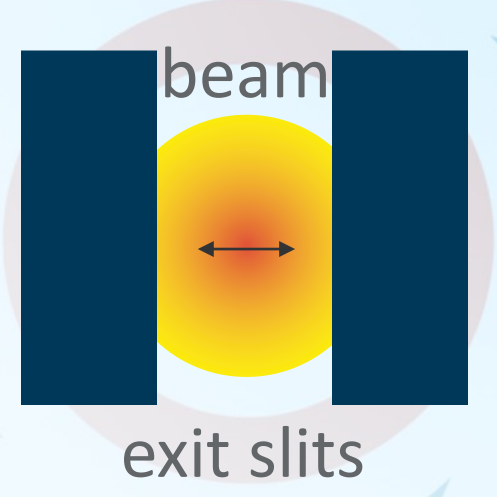
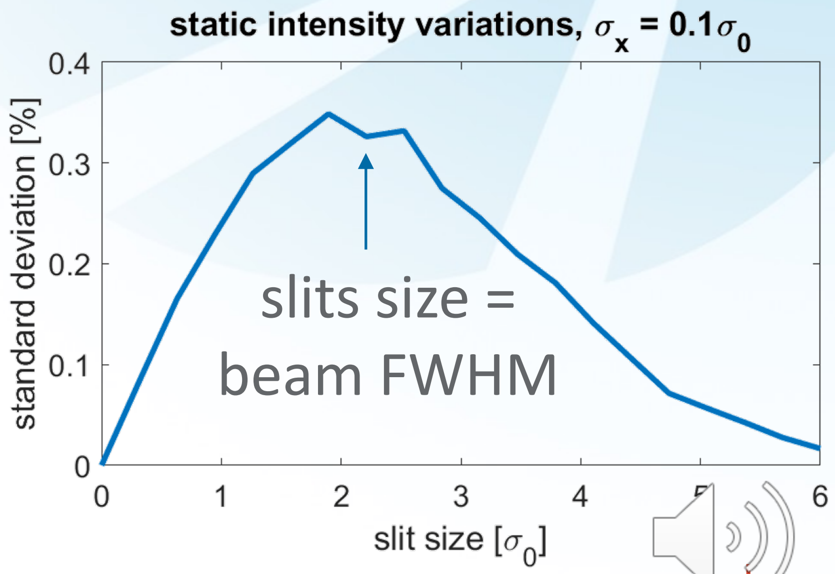
Round beam

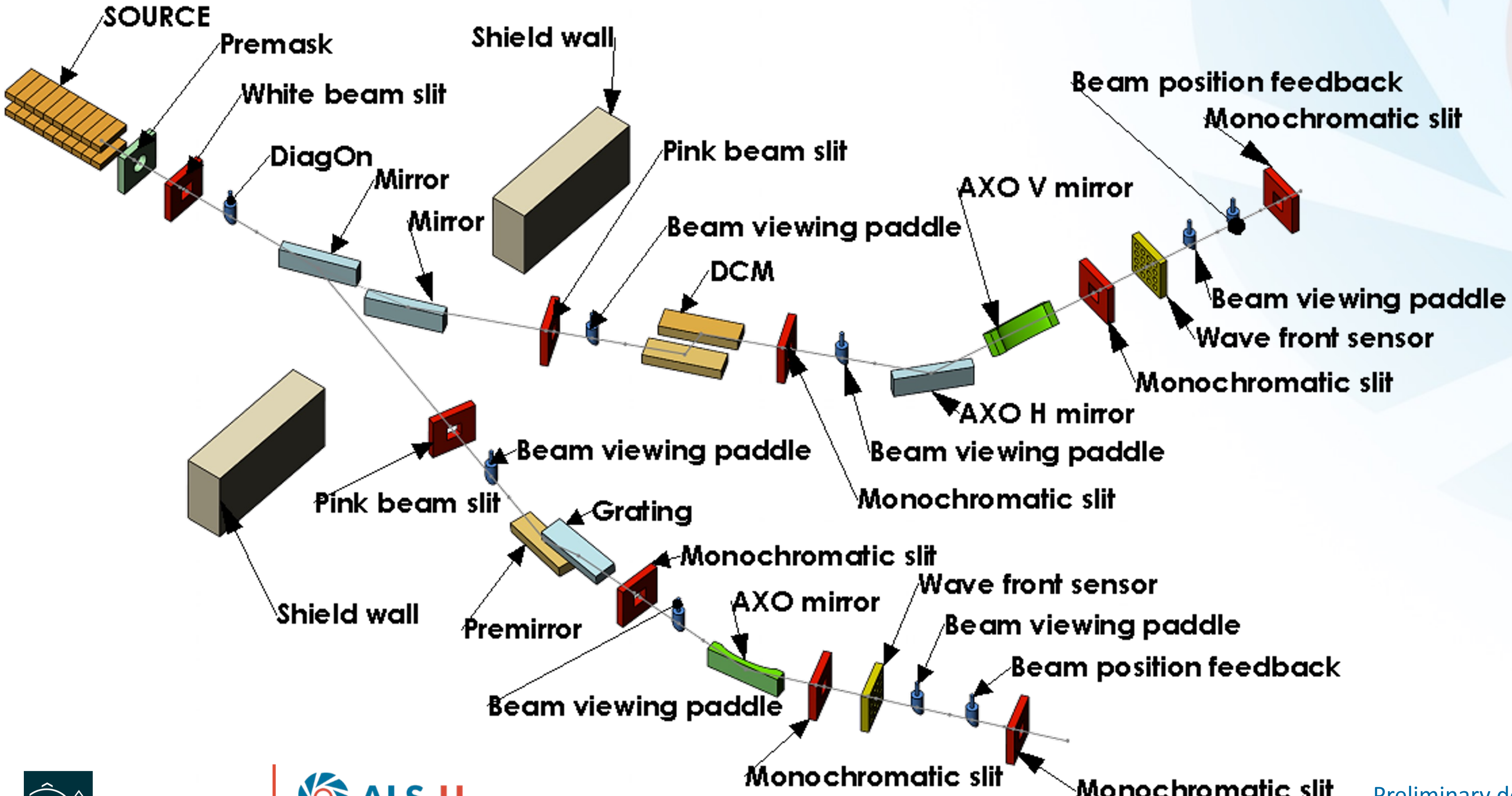
- Exit slits do:
  - spectrally filter the dispersed photon energy
  - spatially filter the beam and select coherence
- Effect on vibrations
  - since the beam is has sharper features, vibrations play a bigger role





Beamlines

Tender beamline



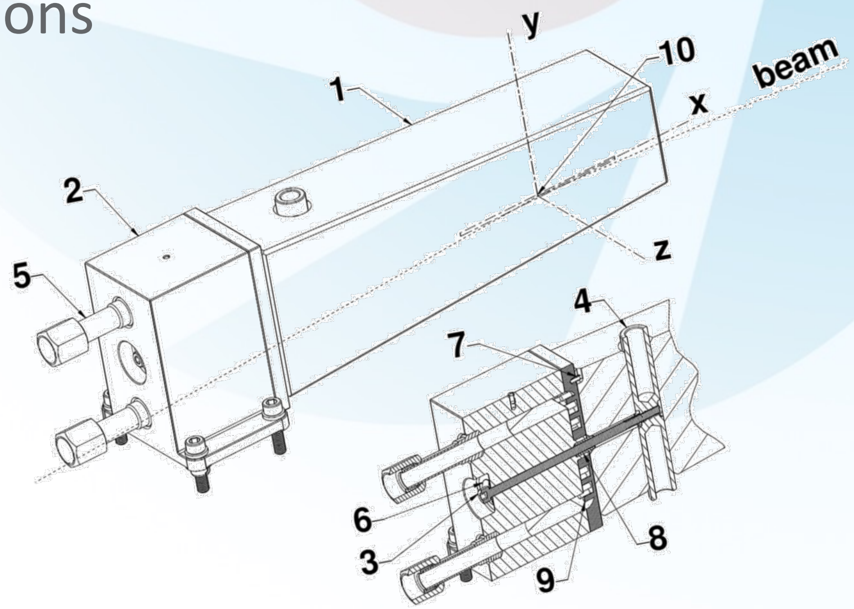
crystal (DCM) Monochromator (2.1–8keV)

grating (VLS) monochromator (1–5keV)

Liquid Nitrogen-cooled white beam mirror

- ALS-U Insertion device: Elliptically Polarizing Undulators
  - fast switching between polarization is such there is a spatially varying heatload

- Using nitrogen cooled white beam mirror to limit aberrations
  - Heatload simulations using SRW/SRCalc
  - FEA simulations using ANSYS
  - Optimization using Strehl ratio
  - Validation using OASYS widget

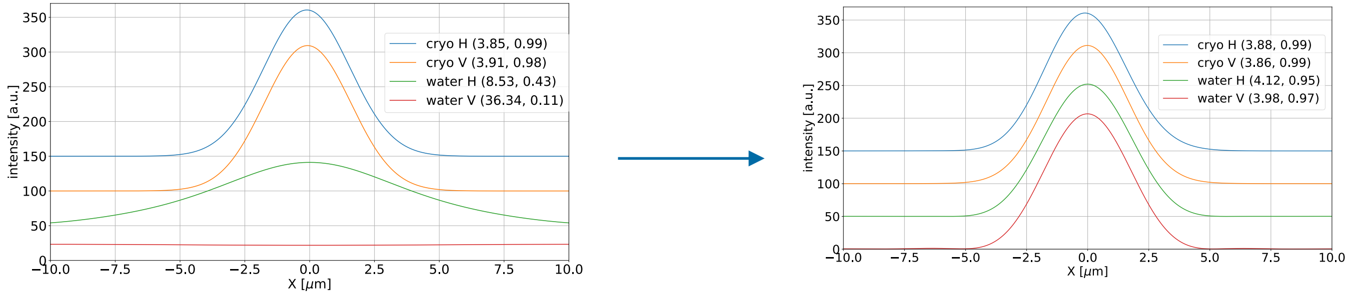


see talk #11491-14

A cantilevered liquid-nitrogen-cooled silicon mirror for the Advanced Light Source Upgrade.
G. Cutler, D. Cocco, E. DiMasi, S. Morton, M. Sanchez del Rio & H. Padmore (2020).
J. Synchrotron Rad. 27, doi.org/10.1107/S1600577520008930.

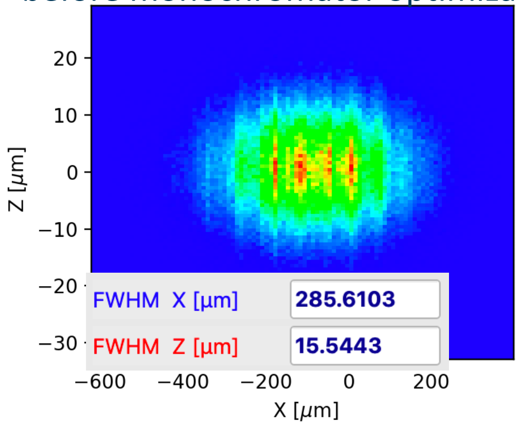
Compensation of thermally-induced aberrations

- White beam mirror
  - compensation using deformable mirror

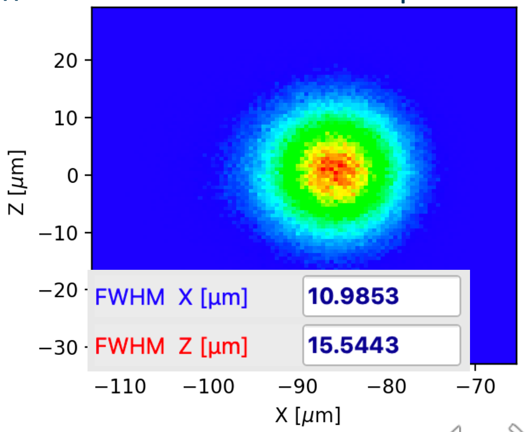


- Monochromator pre-mirror
  - compensation using adaptive VLS grating trajectory

FLEXON at XS111
before monochromator optimization



FLEXON at XS111
after monochromator optimization



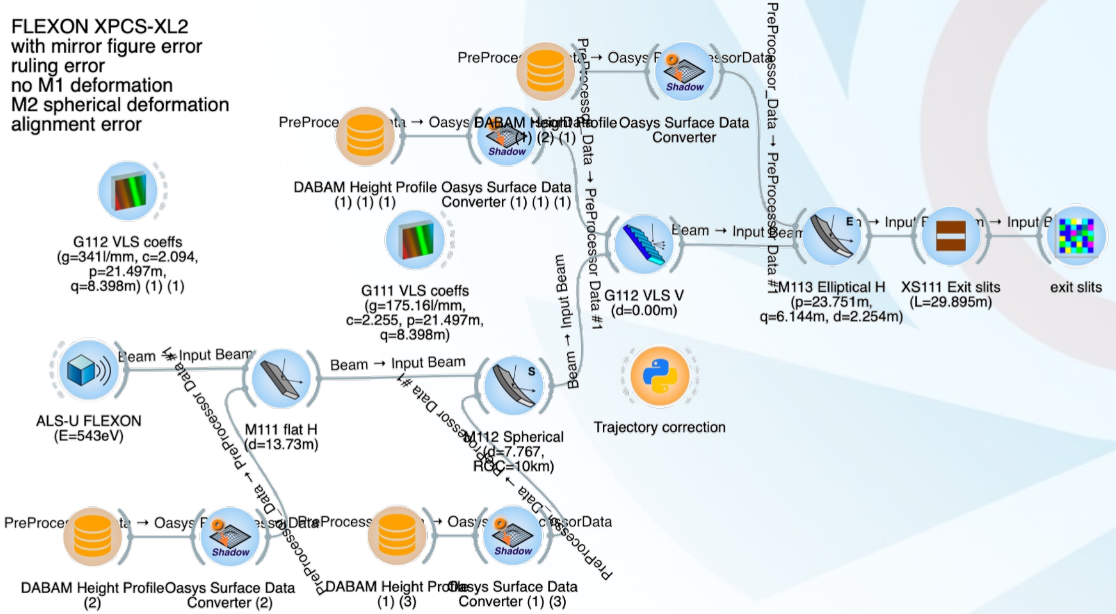
see talk #11493-4

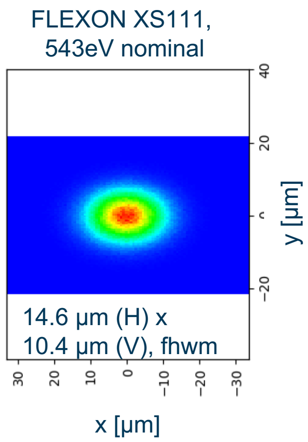
Compensation of heat load deformations using adaptive optics for the ALS upgrade: a wave optics study.
M. Sanchez del Rio, A. Wojdyla, K. A. Goldberg, G. D. Cutler, D. Cocco & H. A. Padmore (2020).
J. Synchrotron Rad. 27, doi.org/10.1107/S1600577520009522

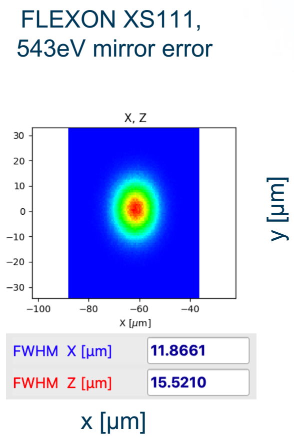
Optical simulations - raytracing

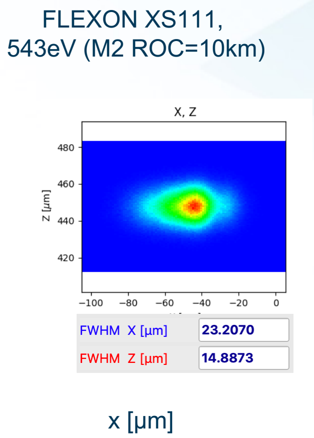
Shadow/OASYS

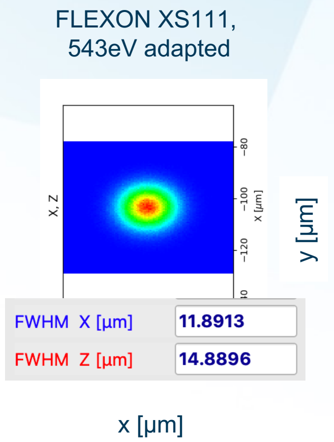
- check nominal size
- figure error
- grating error
- misalignment
- deformation
- corrected beam





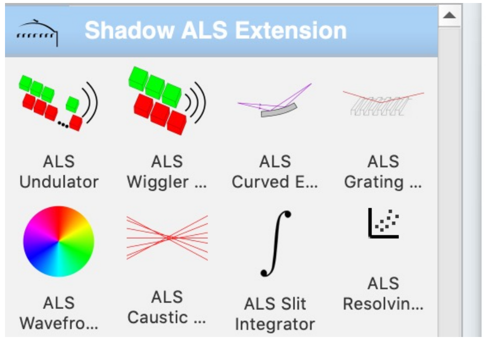


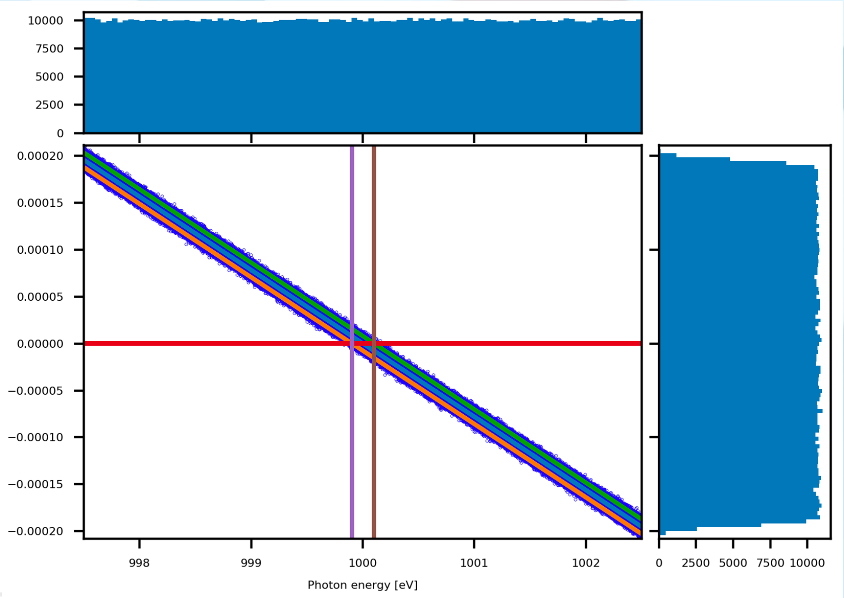


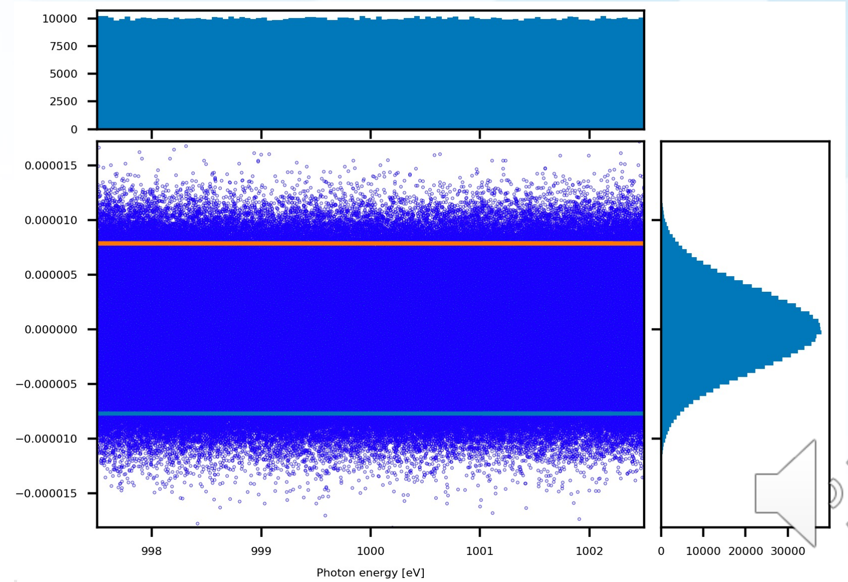


Optical simulations – resolving power

- Resolving power with:
  - mirror error figure
  - ruling error

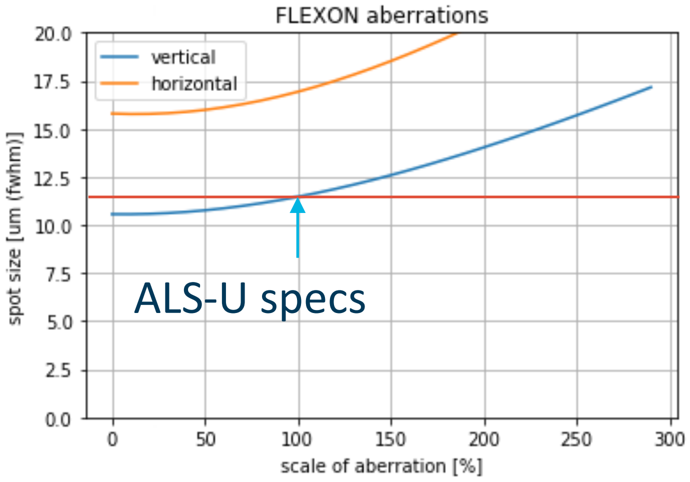


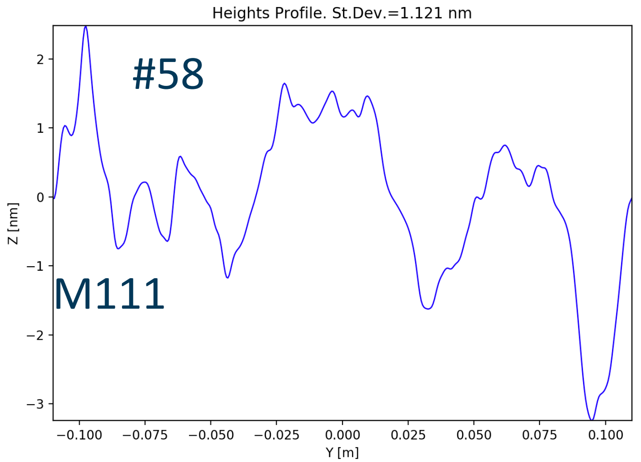




Mirror figure error

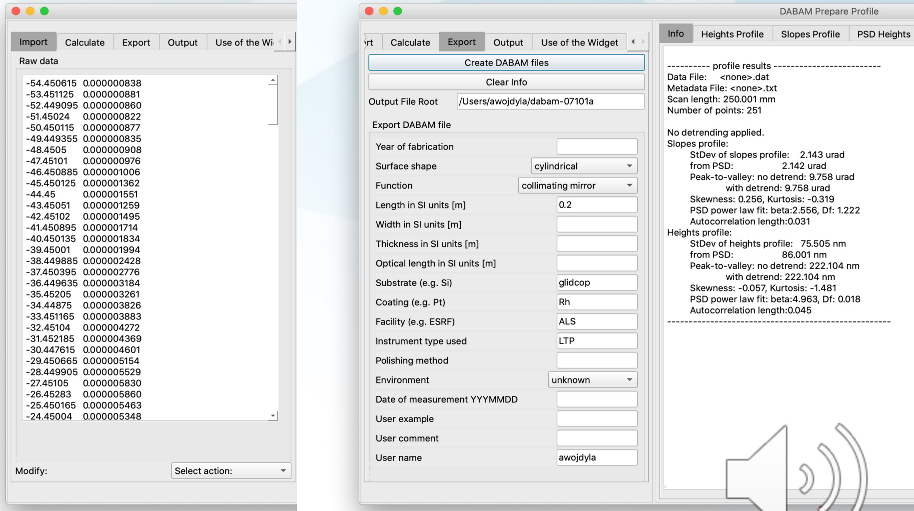
- Superpolished mirrors: not much data available
- depends a lot on vendors,
  need to use "comparable" optics
- DABAM global or local





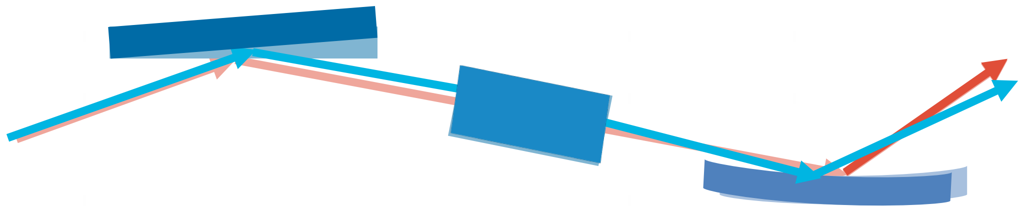
Entry	Shape	Length [m]	Heights St.Dev. [nm]	Slopes St.Dev. [µrad]
58	Plane	0.22	1.121	0.174

new easy import/export tool

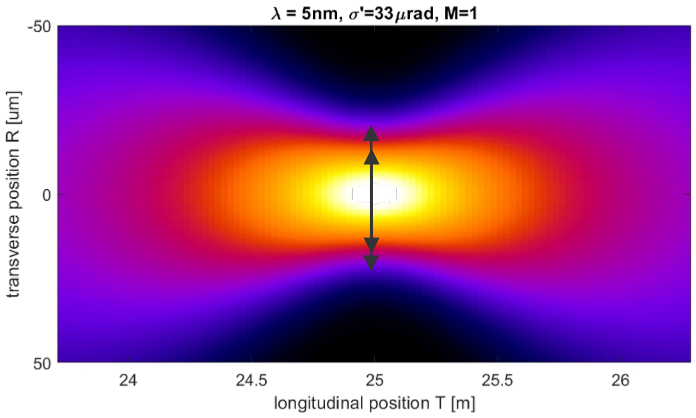


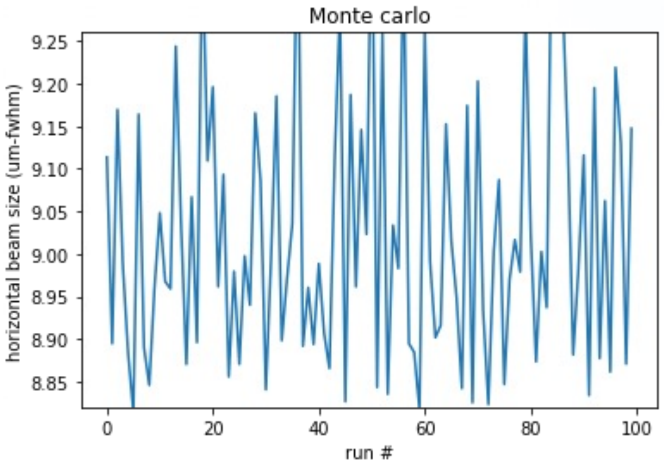
Alignment tolerances

- Limit degrees of freedom but not too much



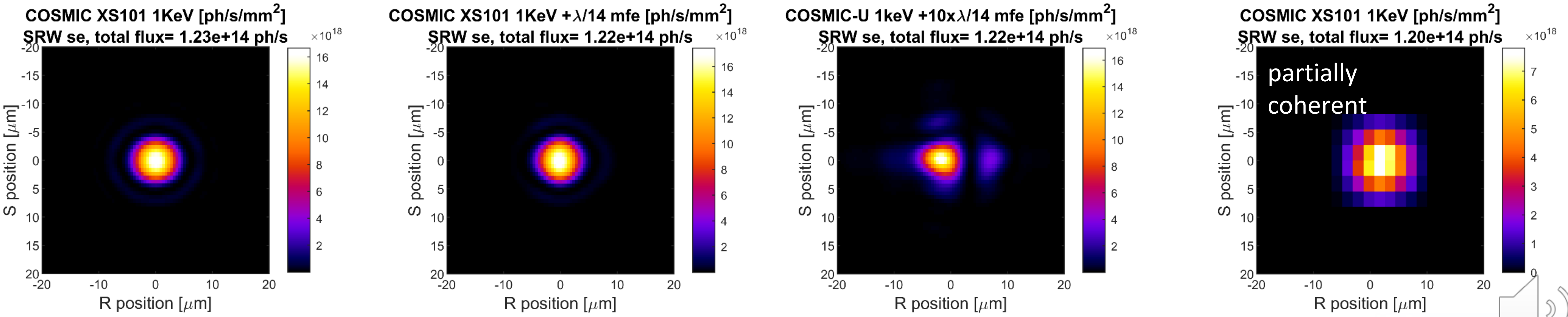
- Tolerance budget: $\Delta\theta = 0.32 \cdot 2L_u \cdot Mag^2\theta/(4\pi q)$ (based on depth of focus)





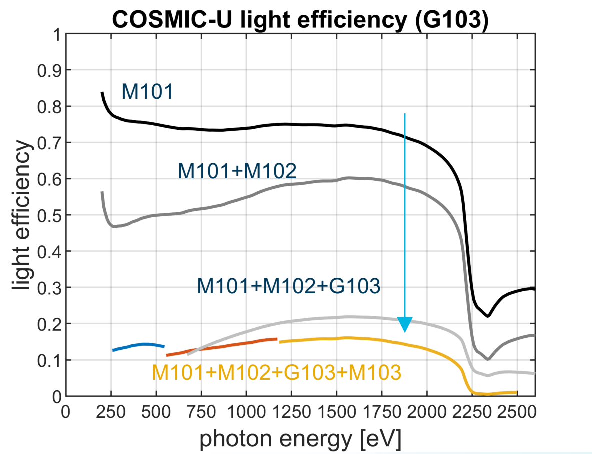
Optical simulations – Wavefront propagation

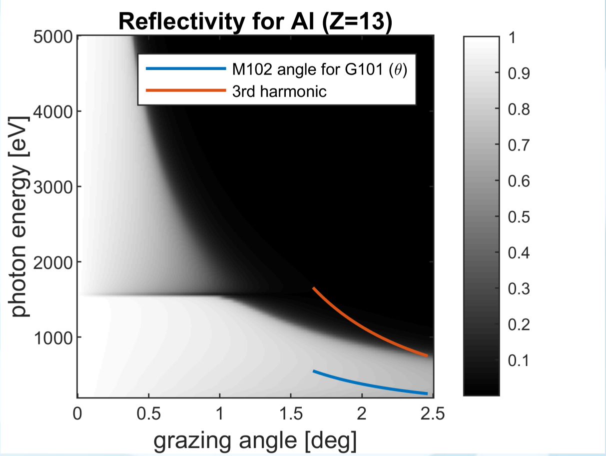
- SRW – tool of reference (within Sirepo or OASYS)
  - evaluation of flux
  - evaluation of height error
  - evaluation of partial coherence (e-beam emittance and E spread)



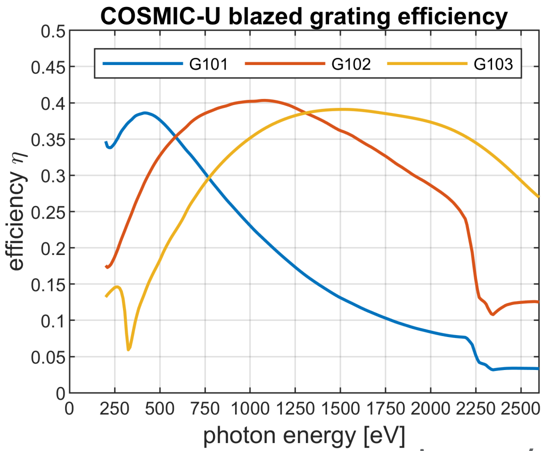
Optical simulations – Light efficiency

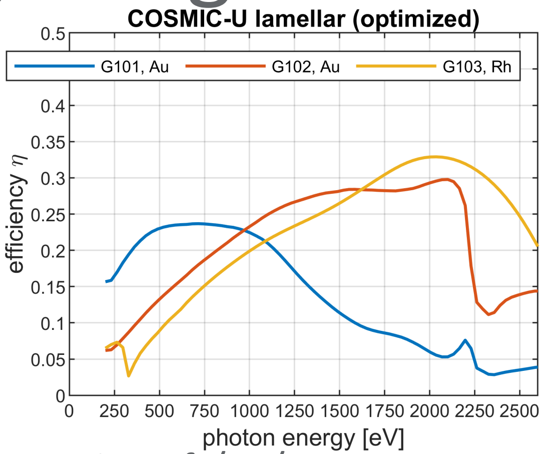
- Mirrors reflectivity from XOPPY or xrt
  - overall efficiency
  - monochromator trajectory
  - harmonic suppression

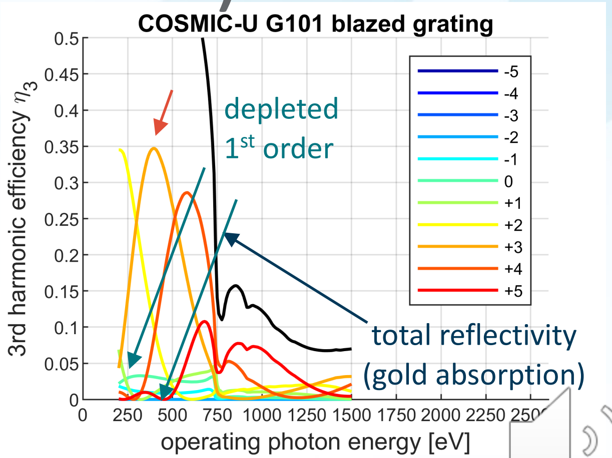




- RCWA simulation for gratings: RETICOLO (Matlab)

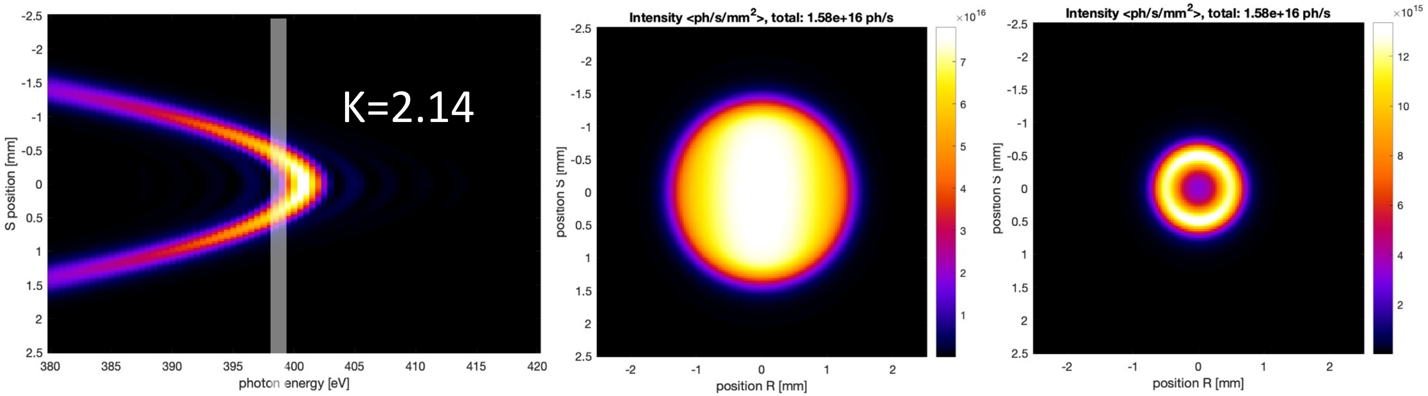




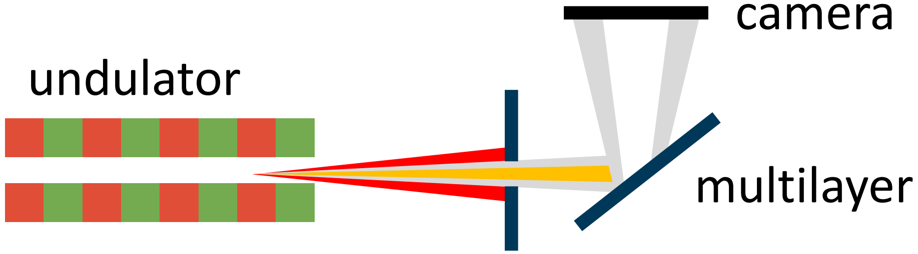


https://www.lp2n.institutoptique.fr/en/equipes-de-recherche-du-lp2n/light-complex-nanostructures

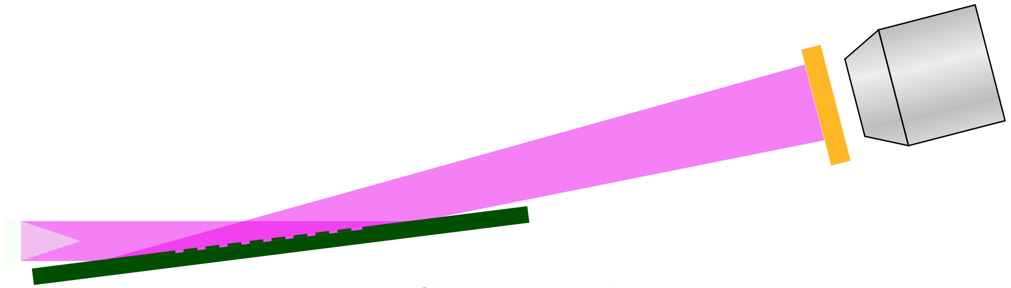
Diagnostics

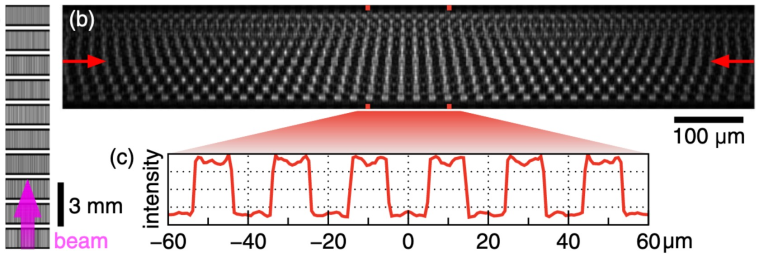


- DiagOn
  - alignment
  - diagnostics of undulator



- Wavefront sensor
  - intermittent wavefront sensor (shearing, 1D)





A reflective binary amplitude grating for soft x-ray shearing and Hartmann wavefront sensors
Kenneth Goldberg, Diane Bryant, Anoine Wojdyla, Michael Helmbrecht, and Eric Gullikson
Optics Letters (2020) doi.org/10.1364/OL.398737

Conclusion

- ALS-U diffraction-limited beamlines have specific constraints, old (reuse of facility) and new (round beam)
- New tools were developed for the preliminary design of ALS-U, covering optical and opto-mechanical aspects
- Diagnostics and correction are important to ensure diffraction-limited beam quality

Collaborations and acknowledgements

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NSLS-II/BNL
Oleg Tchoubar
Steve Hulbert
Mourad Idir

Franz Hennies (Max-IV)
Harry Westfahl Jr (Sirius)
Luca Gregoratti (Elettra 2)
Ray Barrett (ESRF-EBS)
Benedikt Rösner (SLS-II)
Lucia Alianelli (Diamond-II)
Francois Polack (SOLEIL)
…and many others!

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ALS-U Beamline and Optical Systems Team December 2019
(left to right) Albert Sheng, Sooyeon Park, Joe Tocci, Antoine Wojdyla, Dima Voronov, Henry Alvarez, Grant Cutler, Manuel Sanchez del Rio, Alastair MacDowell, Jeff Takakuwa, Simon Morton, Diane Dryant, Howard Padmore, Elaine DiMasi, Ken Goldberg, Arnaud Allezy, Dean Kurilich, Maxime Bergeret, Lyle LaFleche, Tom Swayne.

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