Requirements and major challenges for x-ray optics at NSLS-II

Ruben Reininger & Mourad Idir NSLS-II

ACTOP11, April 5, 2011

Outline

- NSLS-II
- Optics fabrication lab
- Six project beamlines
  - Scientific Interest, technique
  - Optics
- Next beamlines
- Status

NSLS-II March 29, 2011

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Acknowledgments

Y. Cai
IXS
Inelastic X-ray Scattering

A. Fluerasu
CHX
Coherent Hard X-ray Scattering

C. Sanchez-Hanke
CSX
Coherent Soft X-ray Scattering

J. Thieme
SRX
Sub-µm Reso. X-ray Spectrosc.

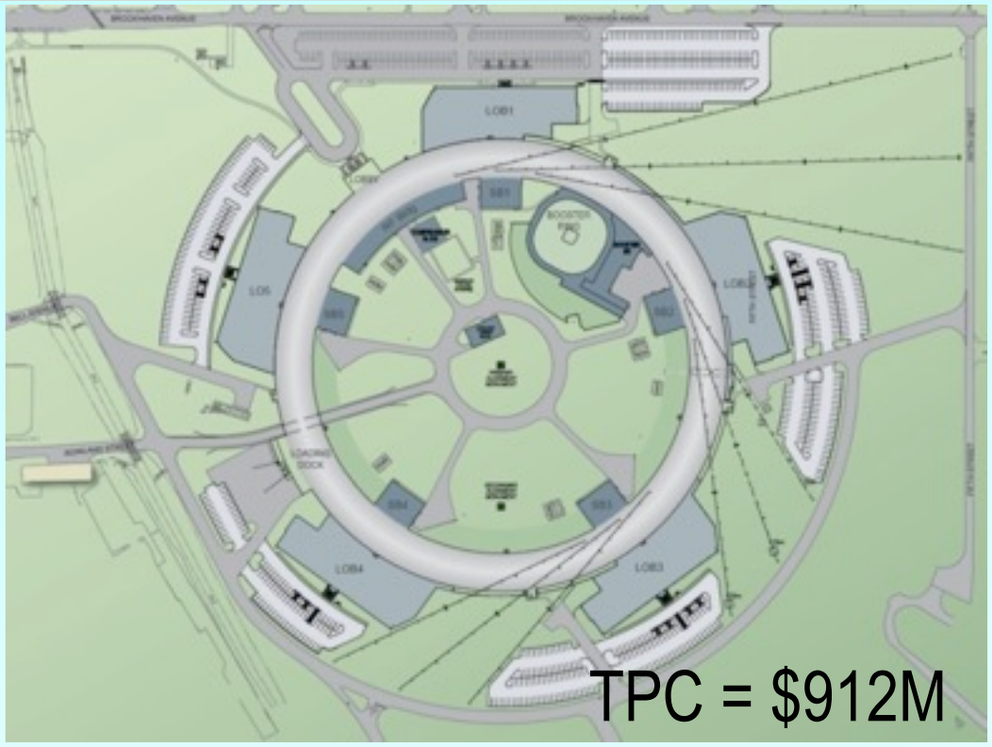
E. Dooryhee
XPD
X-ray Powder Diffraction

Y. Chu
HXN
Hard X-ray Nanoprobe

R. Conley
Optics
Fabrication

NSLS-II: Optimized 3rd Generation SR

- 3 GeV, 500 mA, Circumference 791 m
- Low emittance: ε_x= 0.55, ε_y= 0.008 nm-rad
- High brightness/flux from soft to hard x-rays
- Pulse length (rms) ~15 psec
- 27 insertion device beamlines
- 31 BM / 3PW / IR beamlines
- Full 58 beamlines, plus canted IDs



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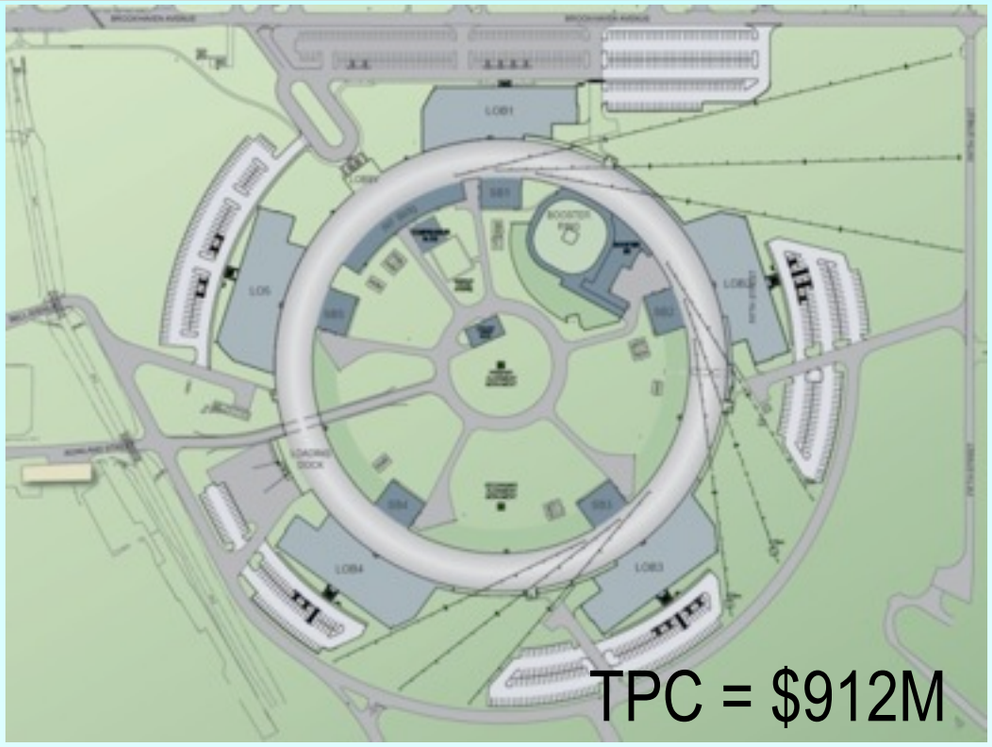
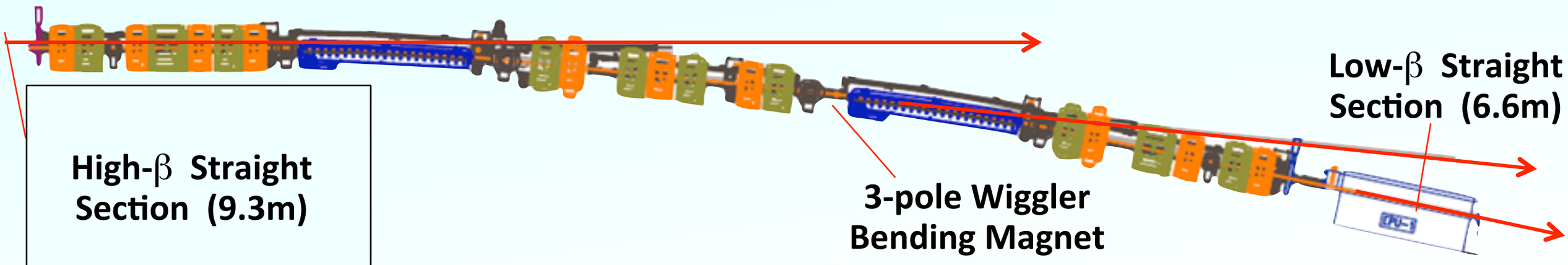
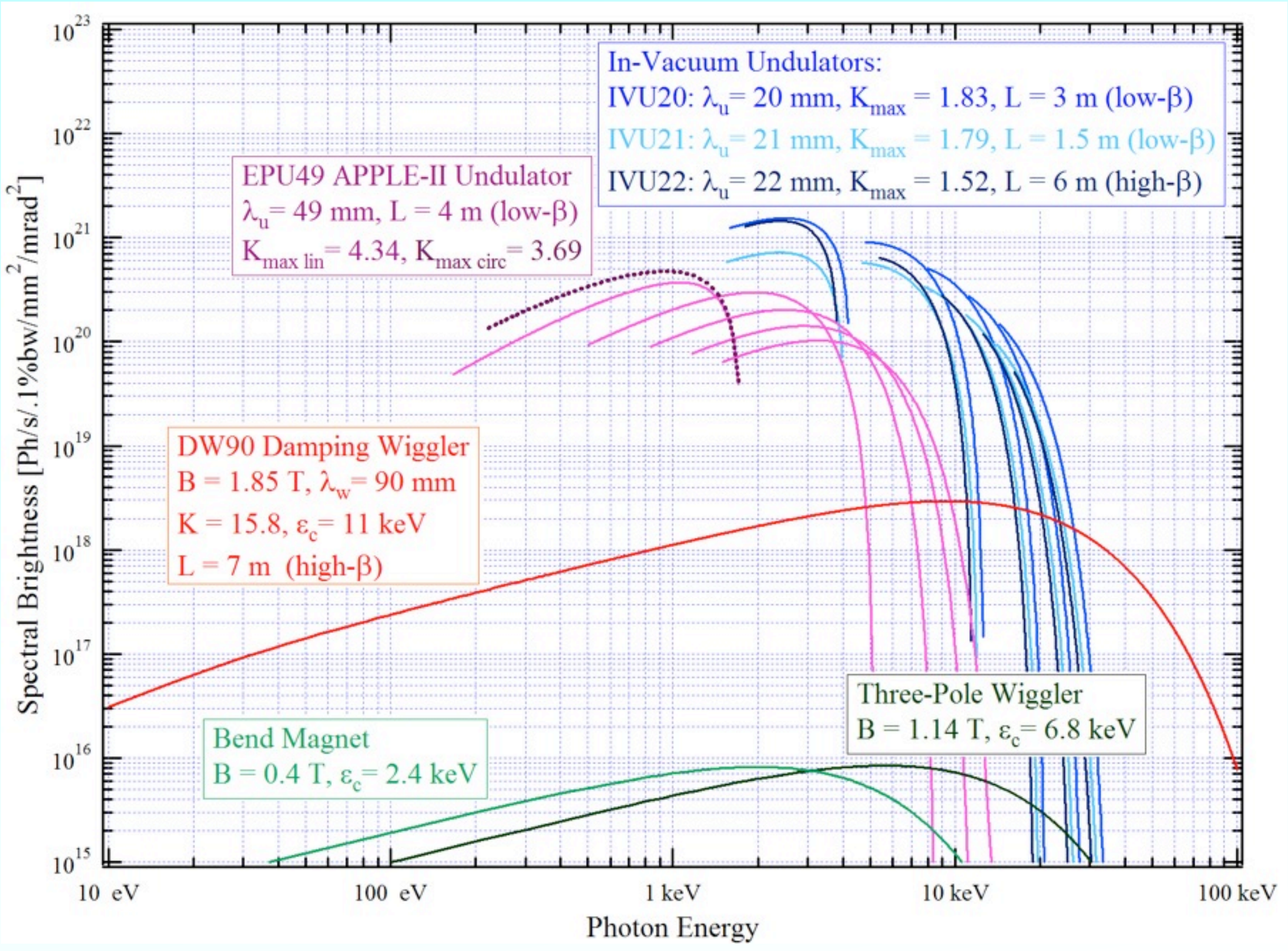


Type of source	Low-β Straight Section (6.6m)	High-β Straight Section (9.3m)	0.4T Bend Magnet	1.14T 3-Pole Wiggler
σ_h (μm)	33.3	107	125	167
σ_h' (μrad)	16.5	5.1	91	98
σ_v (μm)	2.9	5.2	13.4	12.3
σ_v' (μrad)	2.7	1.5	0.80	0.82

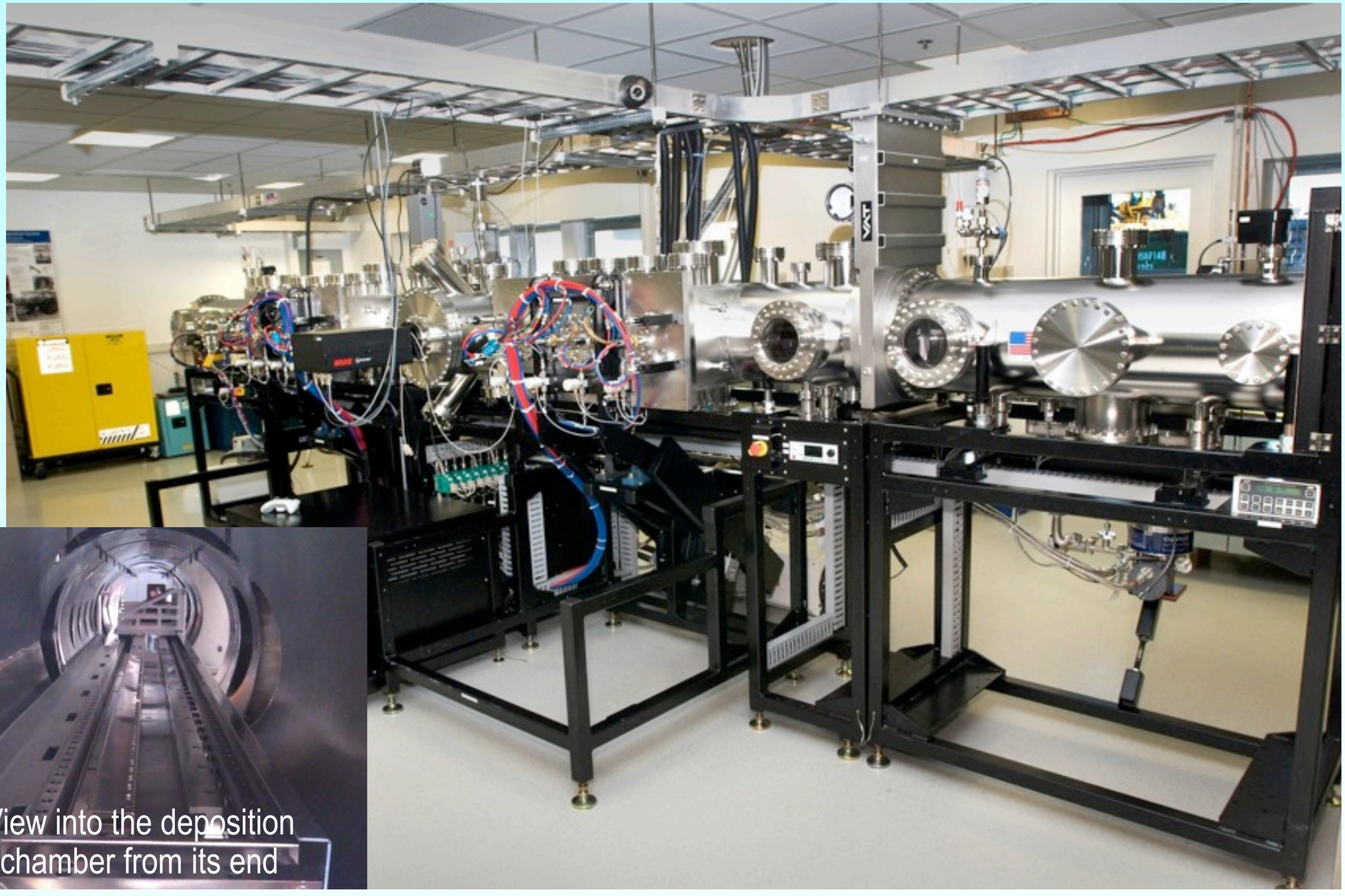


Sources


In-Vacuum Undulators:
IVU20: λu = 20 mm, Kmax = 1.83, L = 3 m (low-β)
IVU21: λu = 21 mm, Kmax = 1.79, L = 1.5 m (low-β)
IVU22: λu = 22 mm, Kmax = 1.52, L = 6 m (high-β)
EPU49 APPLE-II Undulator
λu = 49 mm, L = 4 m (low-β)
Kmax lin = 4.34, Kmax circ = 3.69
DW90 Damping Wiggler
B = 1.85 T, λw = 90 mm
K = 15.8, εc = 11 keV
L = 7 m (high-β)
Three-Pole Wiggler
B = 1.14 T, εc = 6.8 keV
Bend Magnet
B = 0.4 T, εc = 2.4 keV
Spectral Brightness [Ph/s/.1%bw/mm2/mrad2]
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
10^15
10 eV
100 eV
1 keV
10 keV
100 keV
Photon Energy

Optics Fabrication

Optics Fabrication



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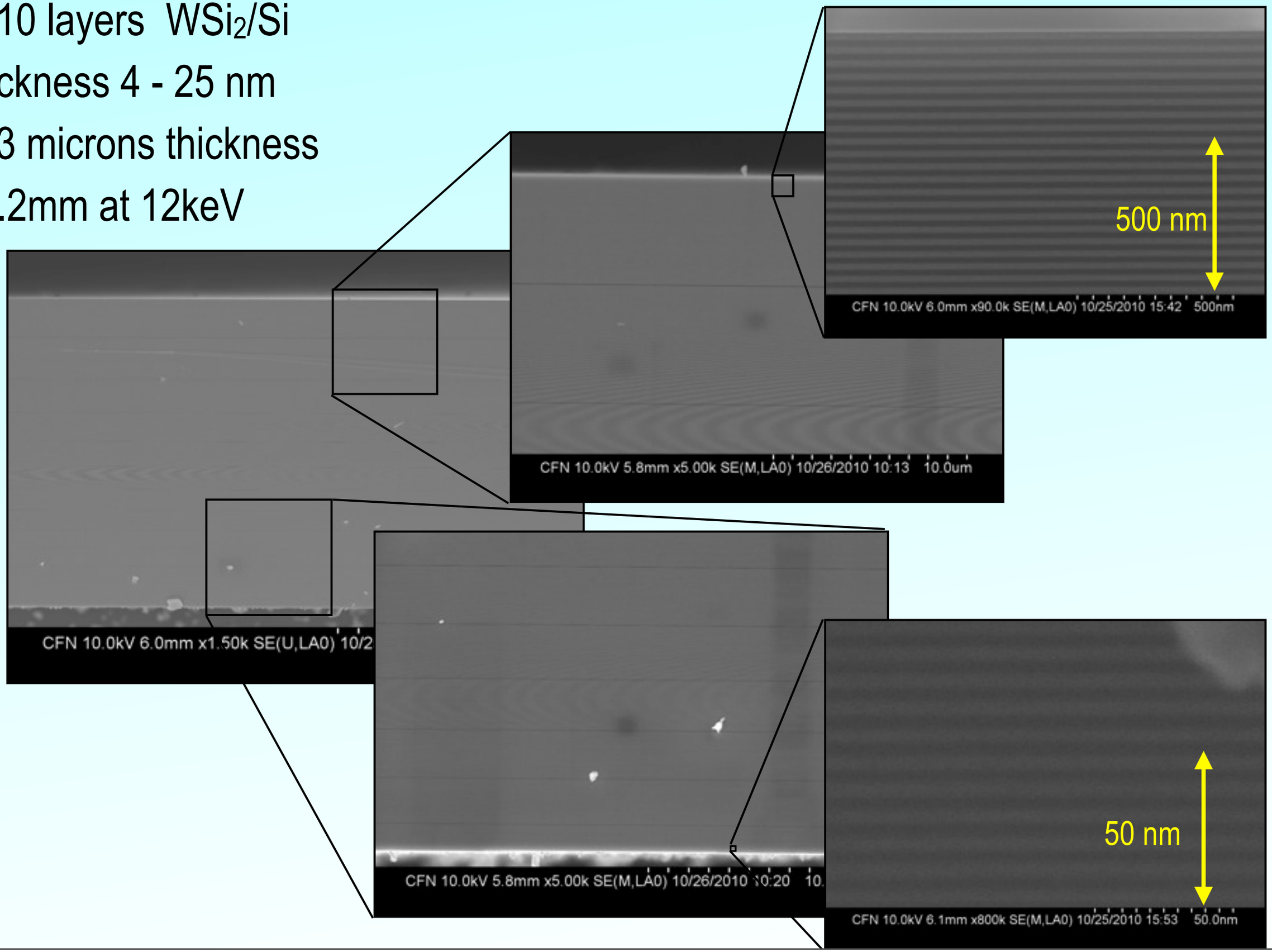
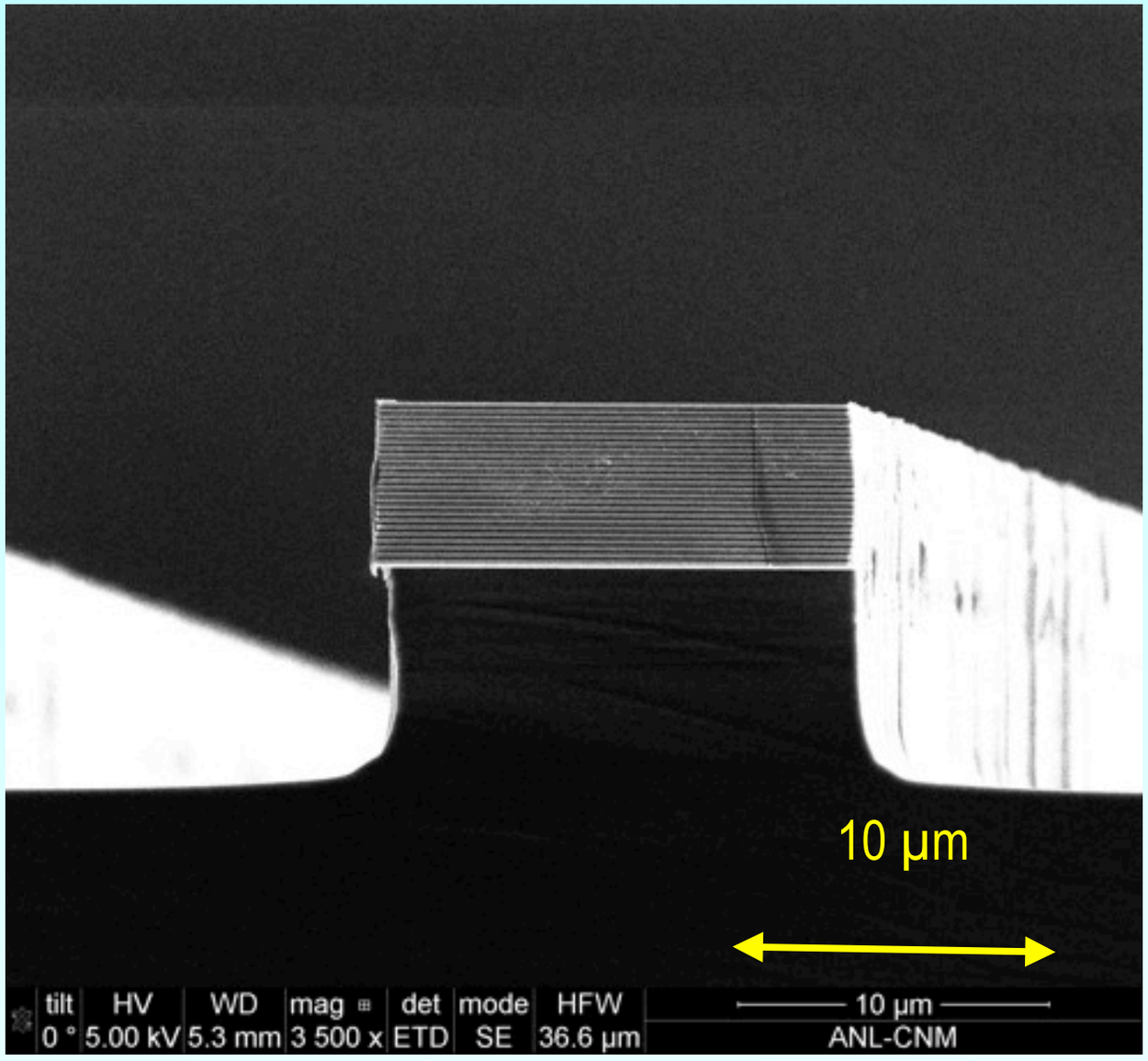
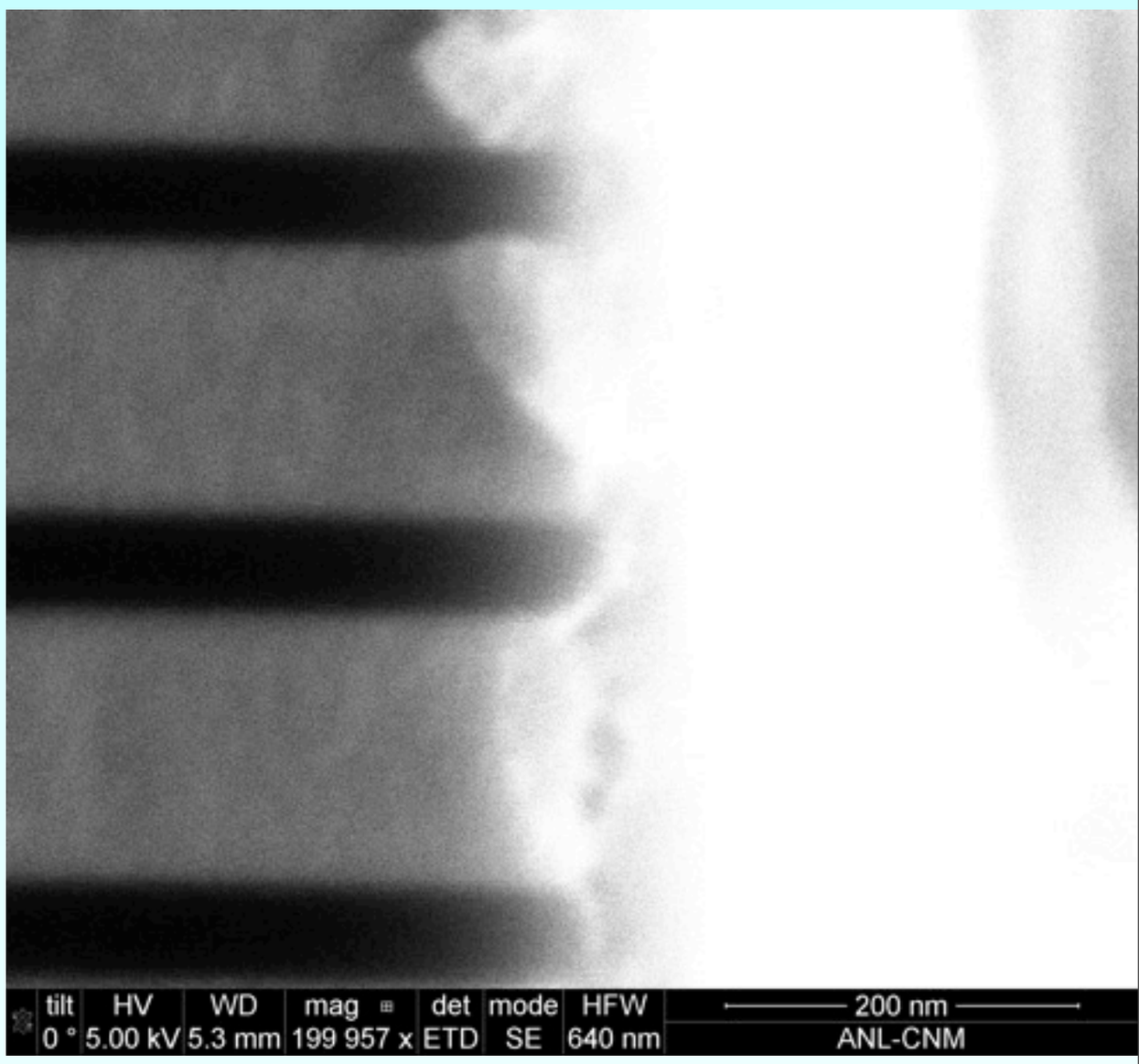
Optics Fabrication: Recent MLL

- 6,510 layers WSi_2/Si
- Thickness 4 - 25 nm
- 43.3 microns thickness
- f=4.2mm at 12keV



MLL: Reactive Ion Etching





Reactive Ion Etching

Mixed fluorinated and chlorinated

(Dry Etching)

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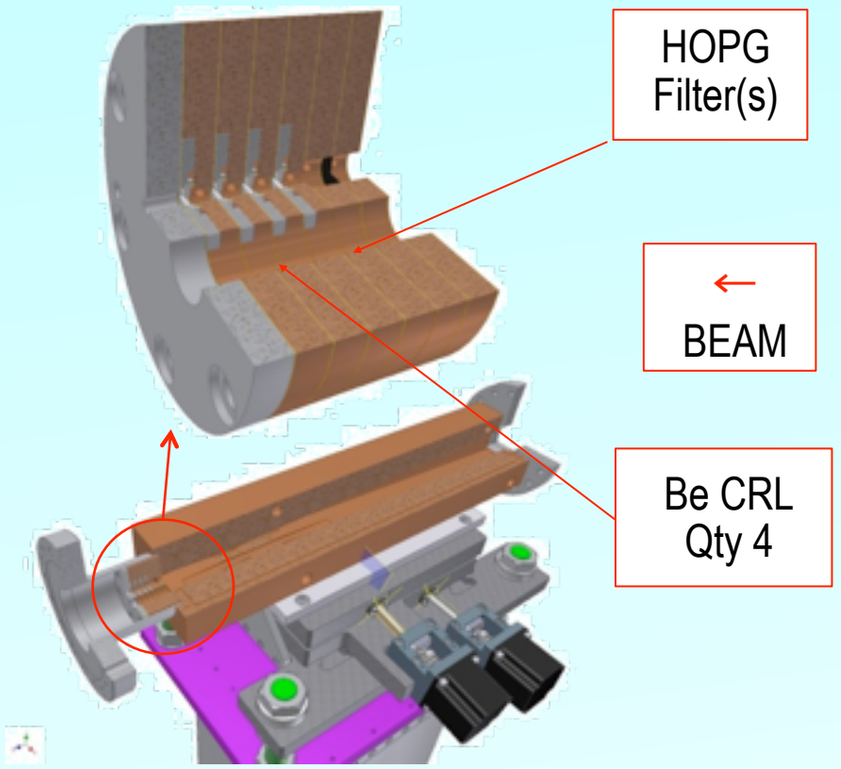
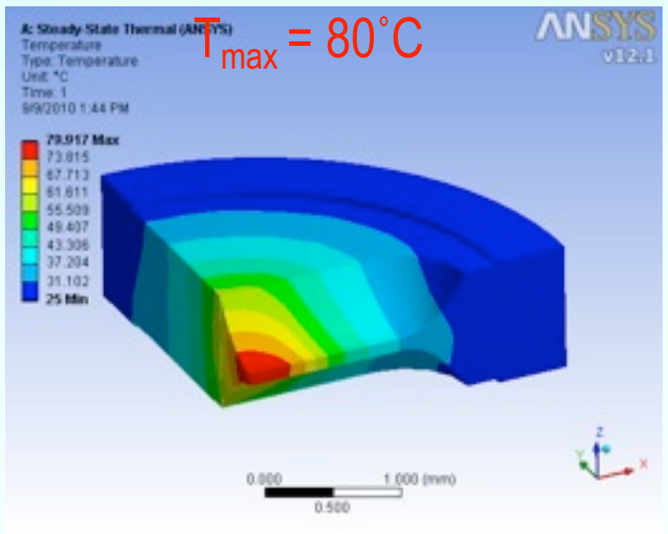
Be Compound Refractive Lens Assembly

- IEX (CHX, HXN)
- Be parabolic CRL ≈1:1 vertical.
- Water cooled, 21 W, 80°C
- Integrated white-beam mask



Be CRL by B. Lengeler



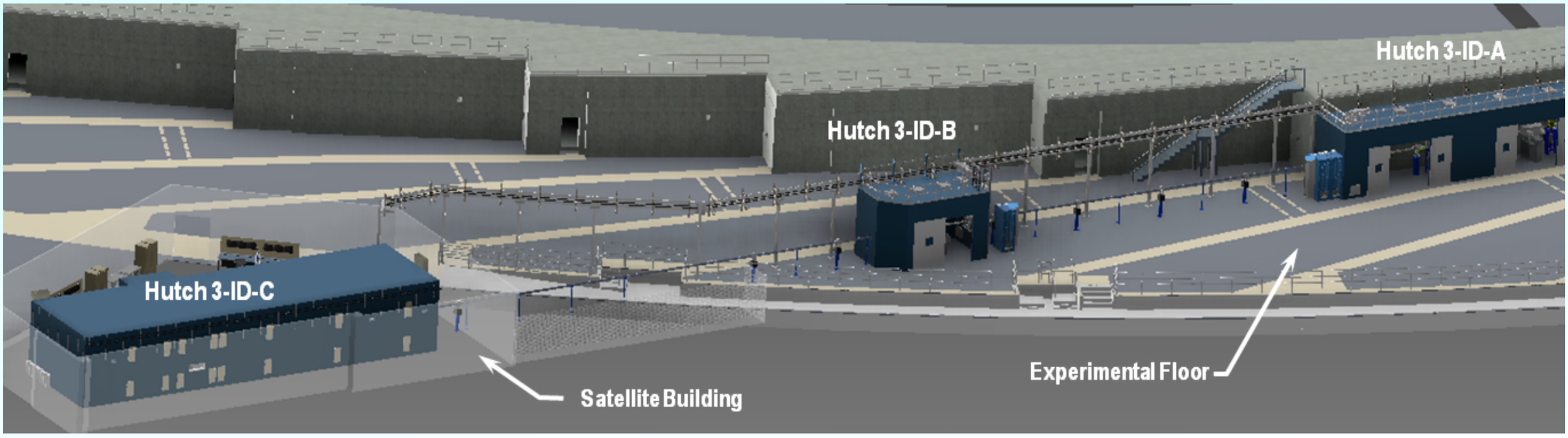
T_{max} = 80˚C

Parameters of the Be Compound Refractive Lenses.

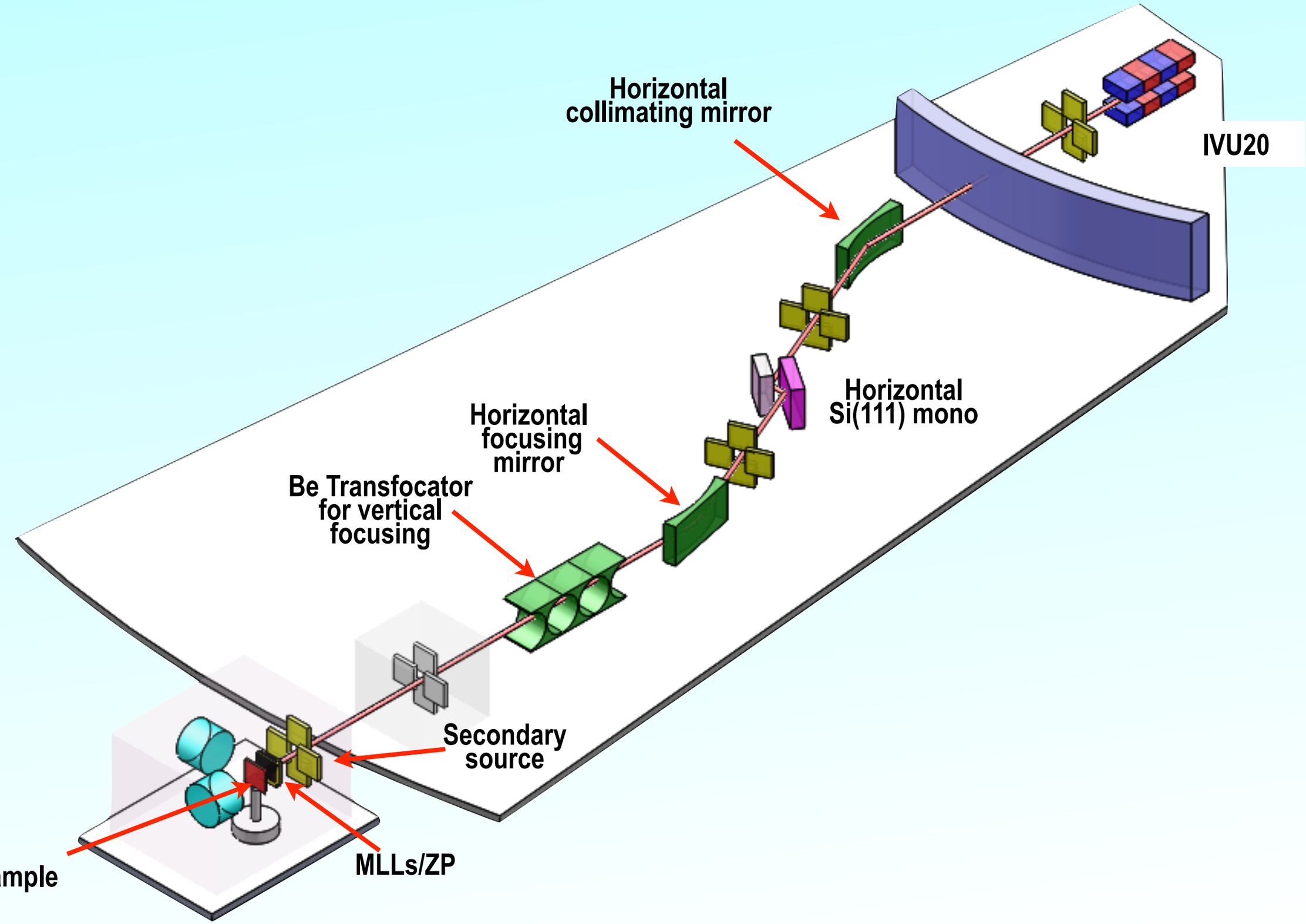
$\delta = 1 - n$	4.09×10^{-6}
Shape	1D parabolic
R (radius of curvature) [mm]	0.300
d (lens apex thickness) [mm]	0.100
N (number of lenses)	4
FD= R/(2Nδ)) [m]	9.176
p (source-CRL distance) [m]	19.200
q (CRL- focus distance) [m]	17.576

HXN: Scientific Interest, Technique

- Scientific interests: Materials science, environmental science, biology
- Scanning fluorescence & diffraction imaging using 10 (1) nm spot.
- Low Beta, IVU20, 3 m
- Experimental hutch: ±0.1°C (long term), ±0.05°C (1 hr period)
- Floor: 1 m concrete

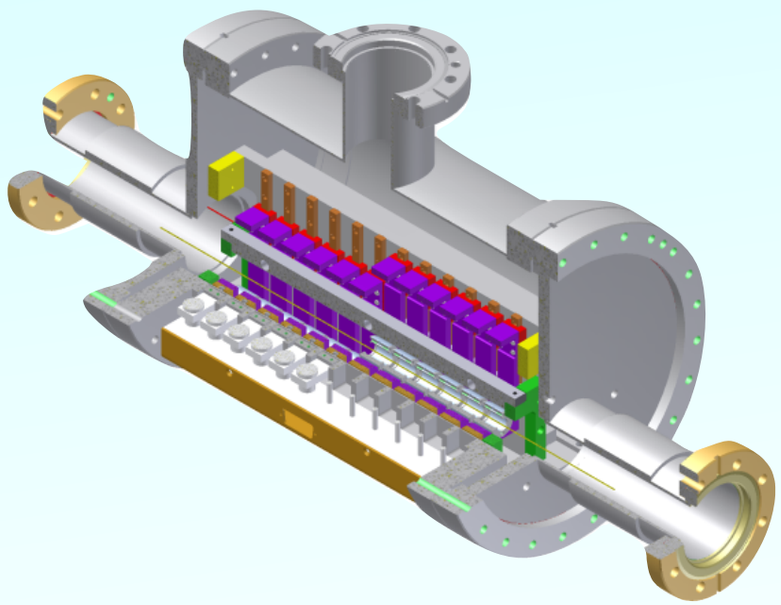


HXN: Beamline Layout



HXN Optics

	Optical Size (mm)	Demag.	Angle (mrad)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
Horizontal Colimating	800	28:∞	3.0	0.5		
Horizontal Focusing	800	∞:61.4	3.0	0.5	174	4.5×10^{13}



- PETRA III transfocator ×1.7
- Vertical focusing to secondary source

Be Transfocator, ESRF results

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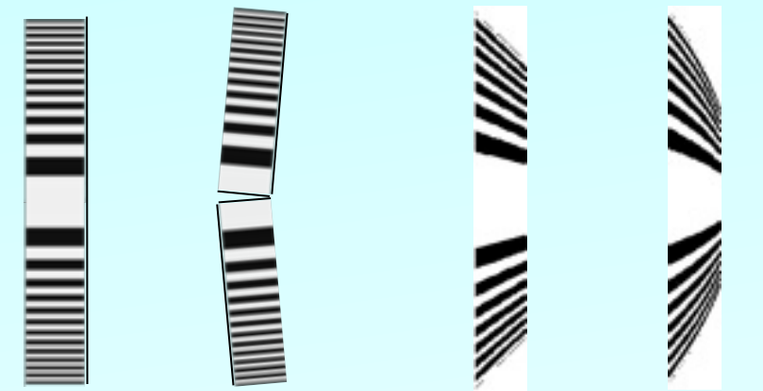
Nanofocusing Optics for the HXN Beamline

Capabilities for the HXN X-ray Microscope

- 10 nm spatial resolution (~2 mm working distance) using MLL optics
- 30 nm spatial resolution (7~14 mm working distance) using ZP optics

Multilayer Laue Lens (MLL)



- **Si (111) provides is sufficient monochromaticity for 10nm focusing.**

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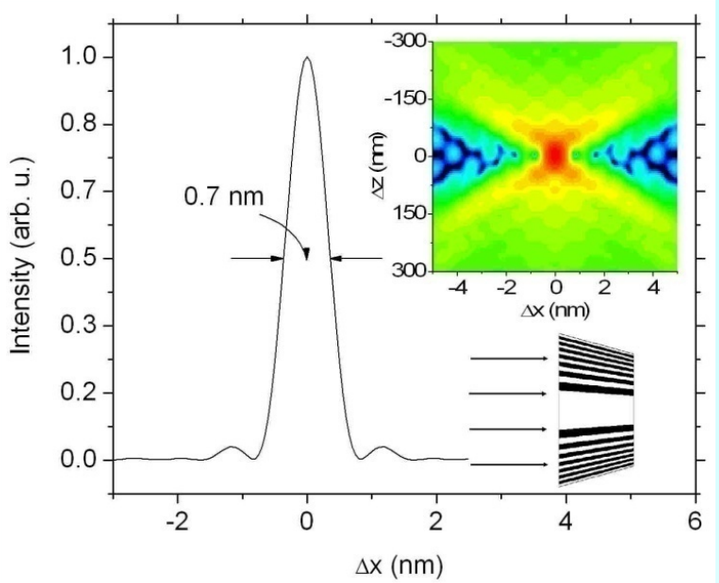

Yan, et al, PRB **76** 115438 (2007)

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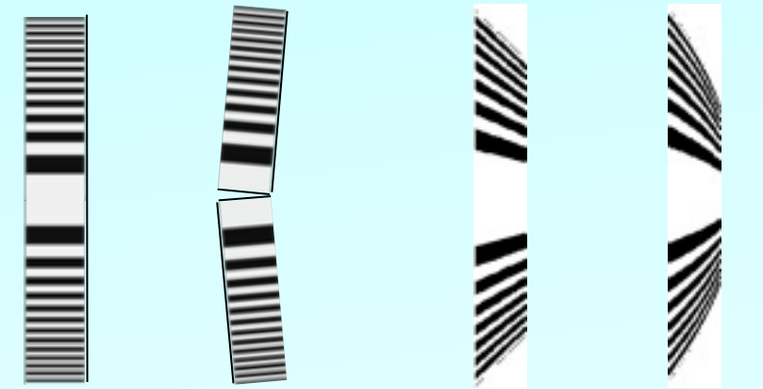

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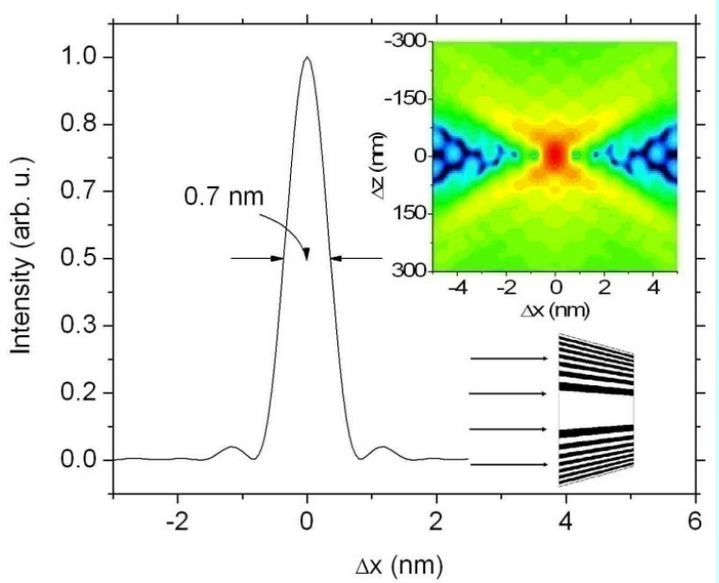

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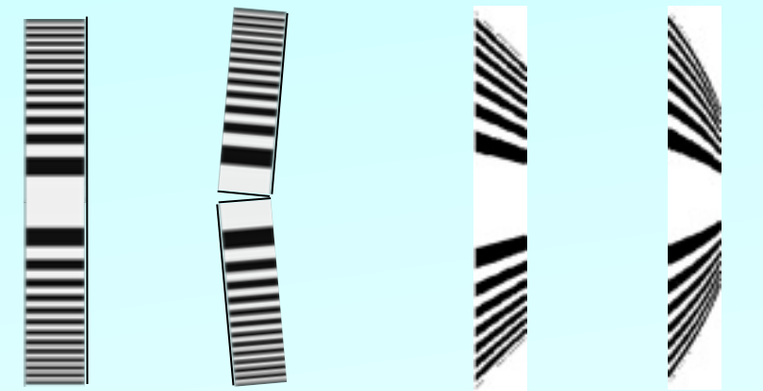

- **Si (111) provides is sufficient monochromaticity for 10nm focusing.**

Optic type	resolution (nm)	energy (keV)	size/ diameter (μm)	depth of focus (μm)	focal length (mm)	working distance (mm)	2D efficiency
tilted flat MLLs	10	10~25	124 at 10keV 62 at 20keV	3.2 at 10keV 6.4 at 20keV	10	2	2.9% at 10keV 4.4% at 20keV
wedged MLL	10	10~25	50 at10keV 25 at 20keV	3.2 at 10keV 6.4 at 20keV	4	2	45% at 10keV 45% at 10keV
ZP	30	6~12	150	17.4 at 6keV 34.8 at 12keV	21.8 at 6keV 43.5 at 12keV	~7 at 6keV ~14 at 12keV	~2% at 10keV

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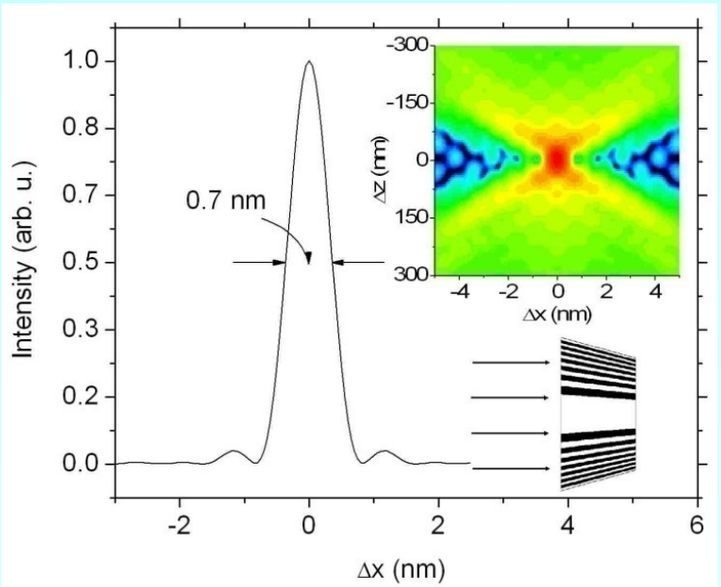

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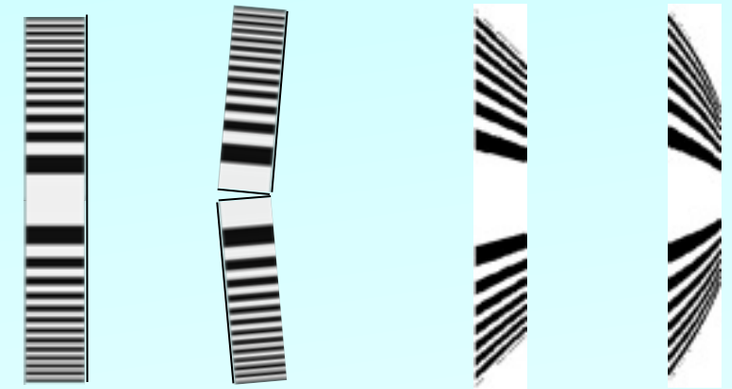

Achieved 25 x 27nm 2D focusing at APS 26-ID using ~20μm MLLs (drN=5nm, ideal focus ~12.5 x 12.5 nm)

- **Si (111) provides is sufficient monochromaticity for 10nm focusing.**

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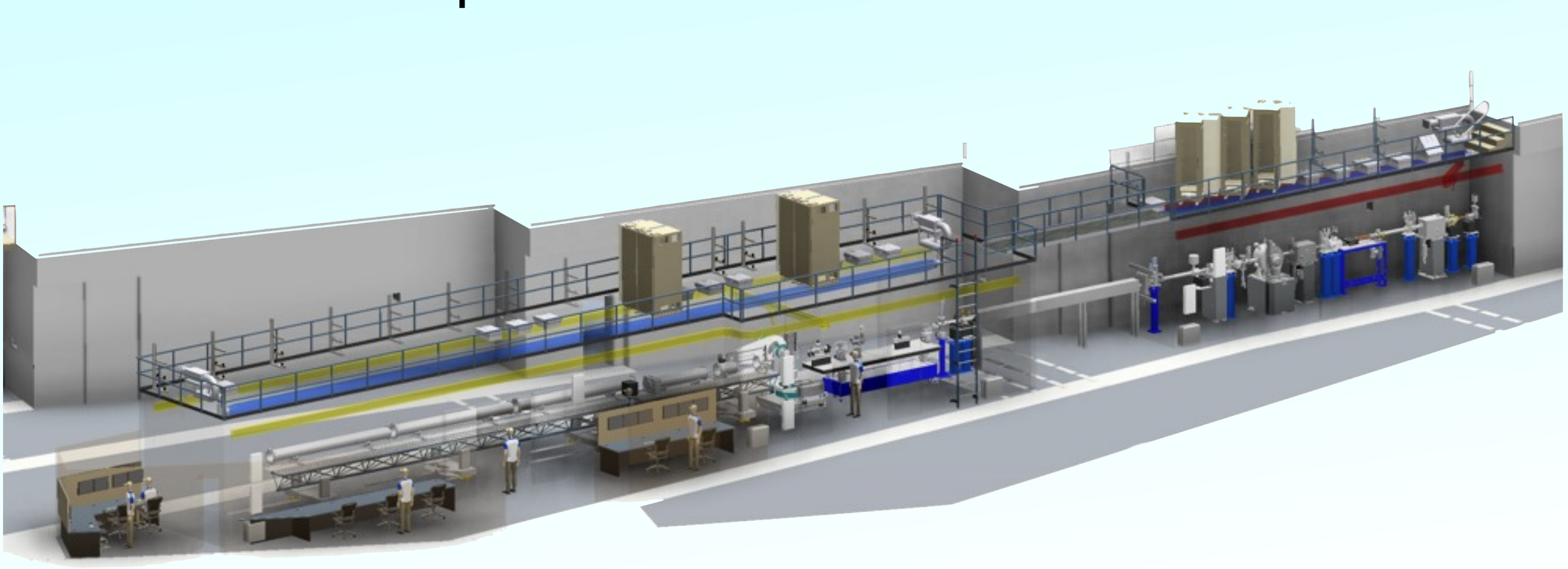
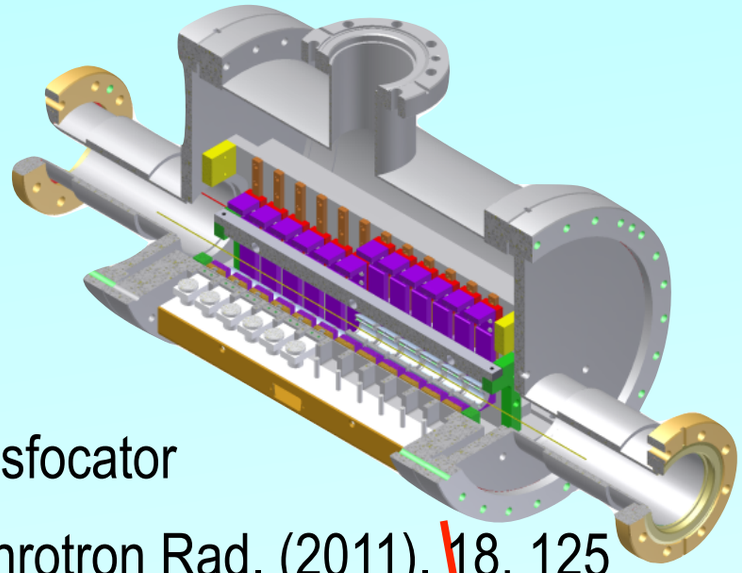
CHX: Scientific Interest, Technique

- Scientific interest: Structure and dynamics of complex materials at molecular scales. Soft matter, biological materials, glasses, inorganics
- Low Beta, IVU20, 3 m, will take 4x4 coherent modes (2-10%)
- XPCS; E=6-15 keV; flux>10^{11} ph/s mono, > 10^{12} ph/s pink beam
- SAXS, WAXS, GI-SAXS
- Full-field CDI and μ-beam-SAXS



CHX: Beamline Layout I



Be Transfocator

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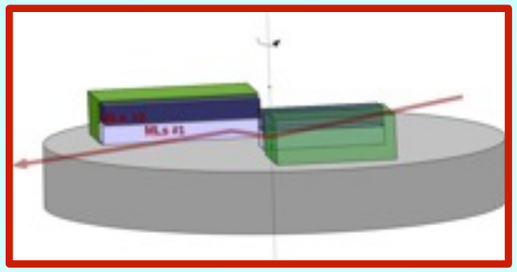
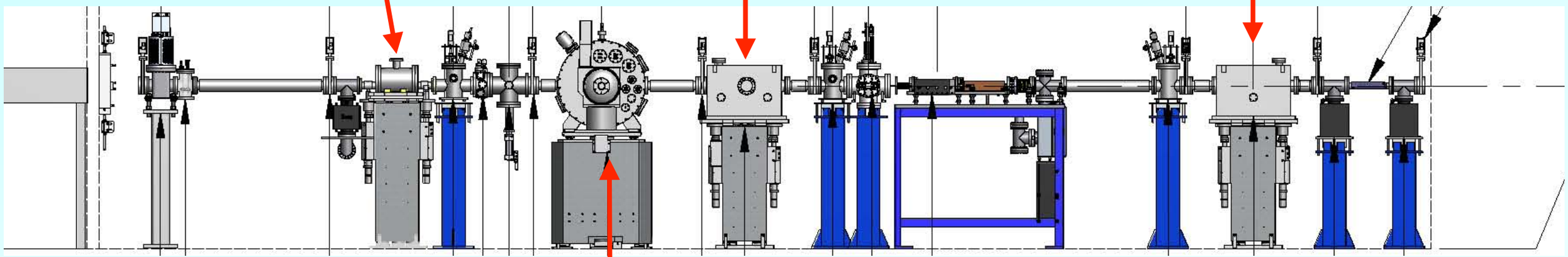
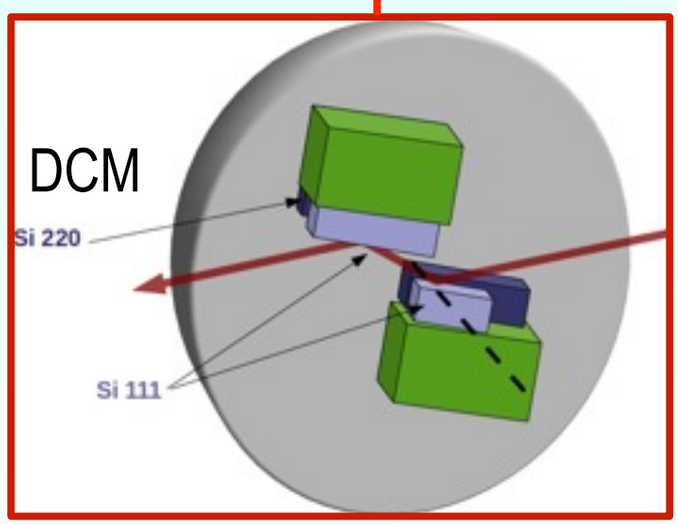
Multilayer mono



Plane mirror





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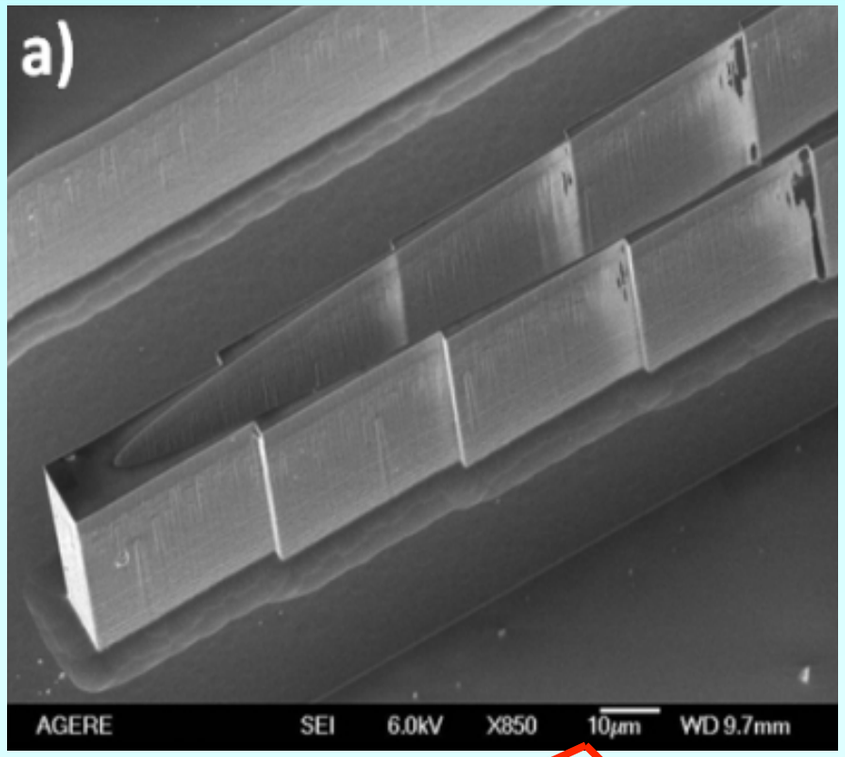
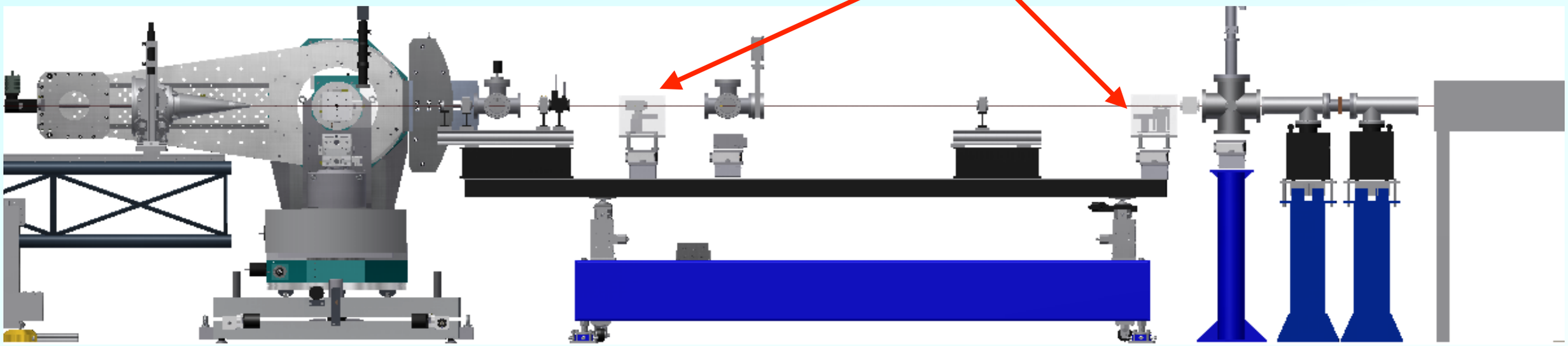
CHX: Beamline Layout II

Si kinoforms

K. Evans-Lutterodt et al.

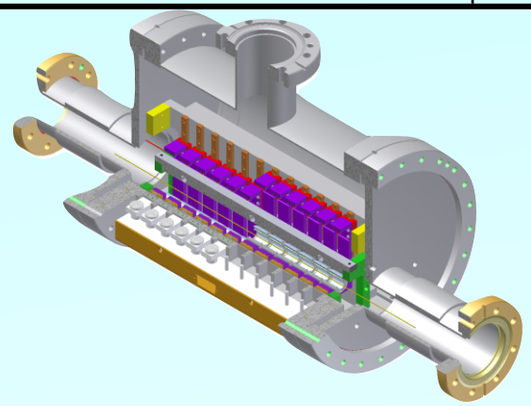
J. Synchrotron Rad. (2010) 17, 314





CHX Optics

	Optical Size (mm)	Demag.	Angle (mrad)	SE RMS (µrad)	Size (µm)	Flux (Phot/s)
Plane: Horizontal	300		3.1	0.3		



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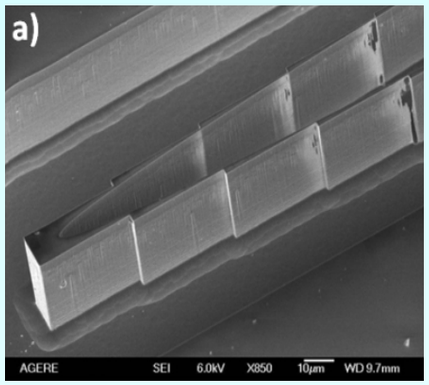

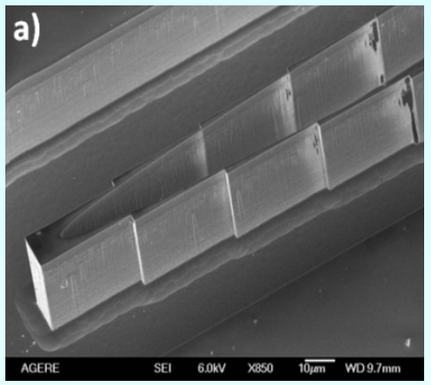

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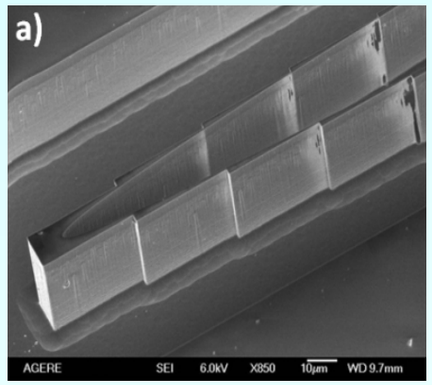
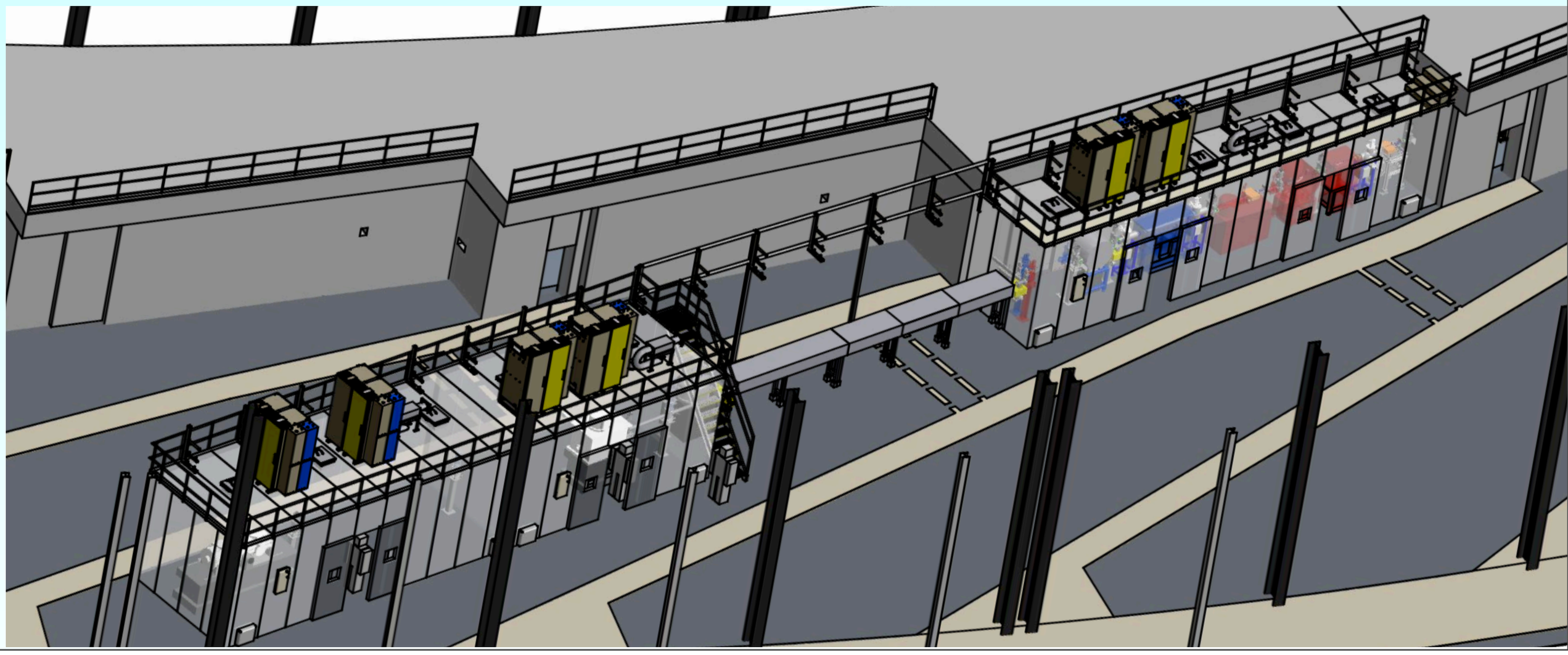


- XPCS-SAXS
- PETRA III transfocator, vertical ×0.3
- Kinoform horizontal ×0.1
- Slits
- 10µm @ sample

- XPCS-WAXS
- Kinoform vertical ×0.1
- Kinoform horizontal ×0.03
- Slits
- 2 µm @ sample

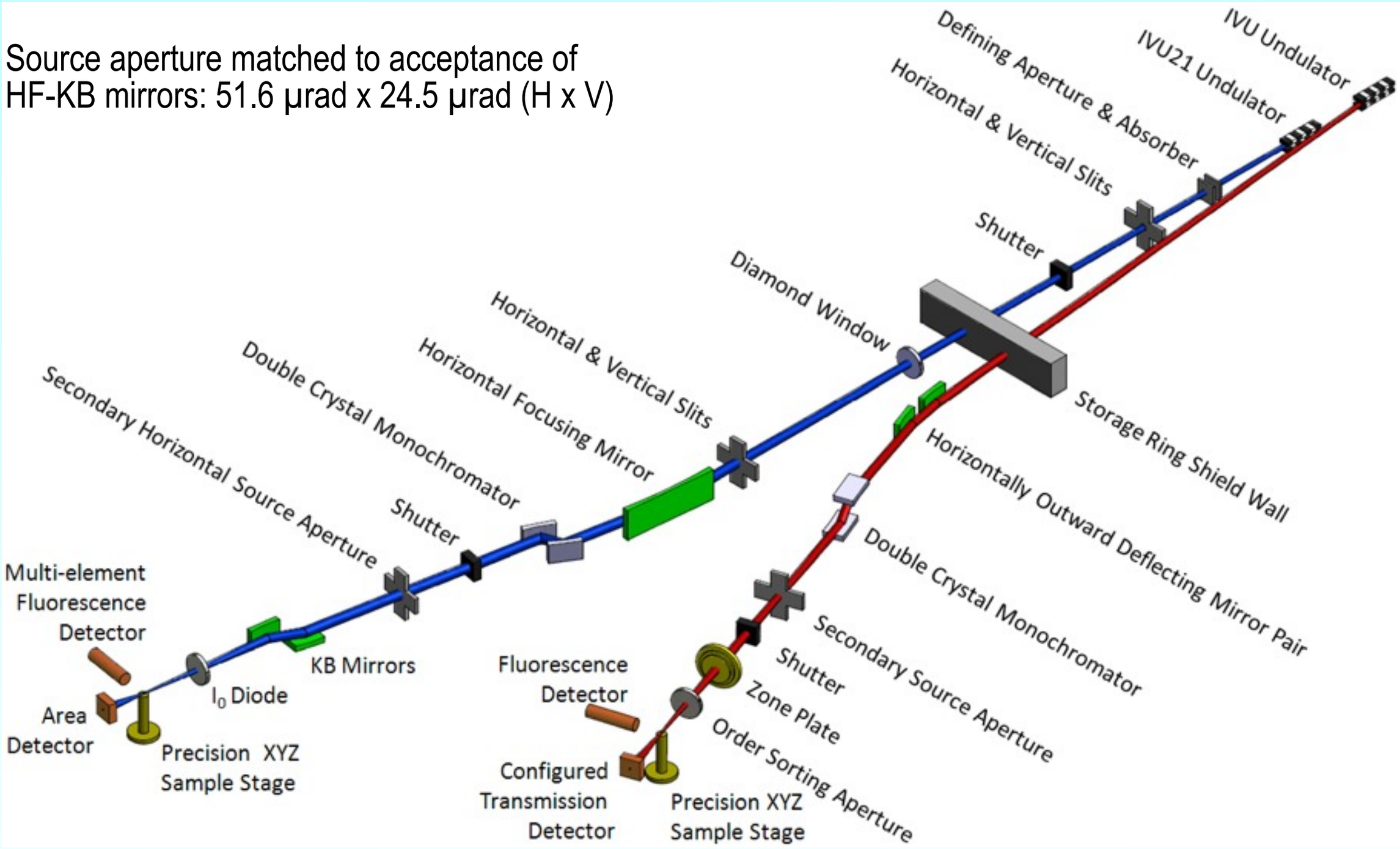
SRX: Scientific Interest, Technique

- Scientific interest: Sub-micron imaging and spectroscopy of elemental distribution in chemical and energy science, materials science, earth and environmental science, life science.
- Low Beta, IVU21,1.5 m
- Energy range 4.65 keV ≤ E ≤ 23 keV, flux > 10^{13} phot/sec.



SRX: Beamline Layout

Source aperture matched to acceptance of
HF-KB mirrors: 51.6 µrad x 24.5 µrad (H x V)



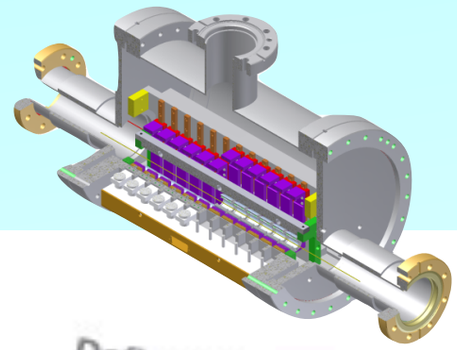
SRX Optics

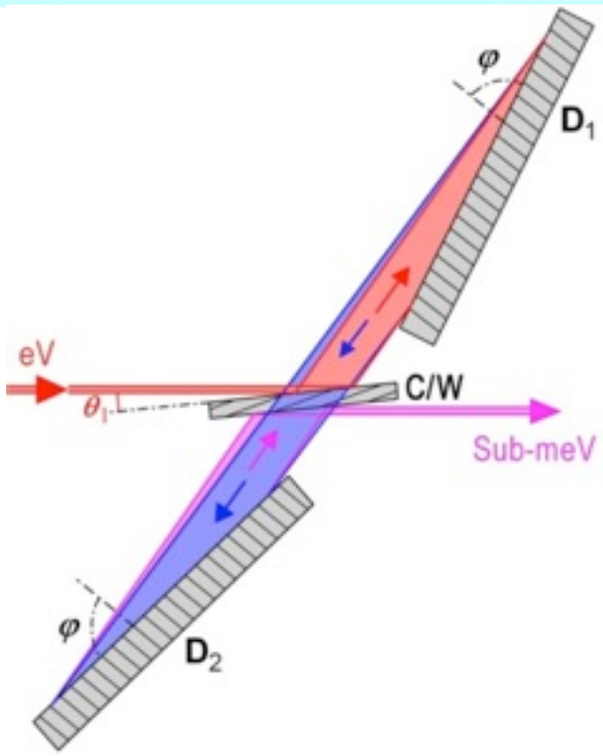
	Optical Size (mm)	Demag.	Angle (mrad)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
HFM: Elliptical Cylinder	680	33:17	2.5	0.5 (0.3)		
KBVF: Elliptical Cylinder (Bender)	350	65:0.7	3.5	0.3 (0.1)	0.7	
KBHF: Elliptical Cylinder (Bender)	300	16:0.3	3.5	0.3 (0.1)	0.9	$>10^{13}$
KBVH: Elliptical Cylinder	142	66:0.14	2.5	0.1 (?)	0.036 (DL) (12 keV)	
KBHF: Elliptical Cylinder	60	16:0.06	2.5	0.1 (?)	0.036 (DL) (12 keV)	10^{11}-10^{12}

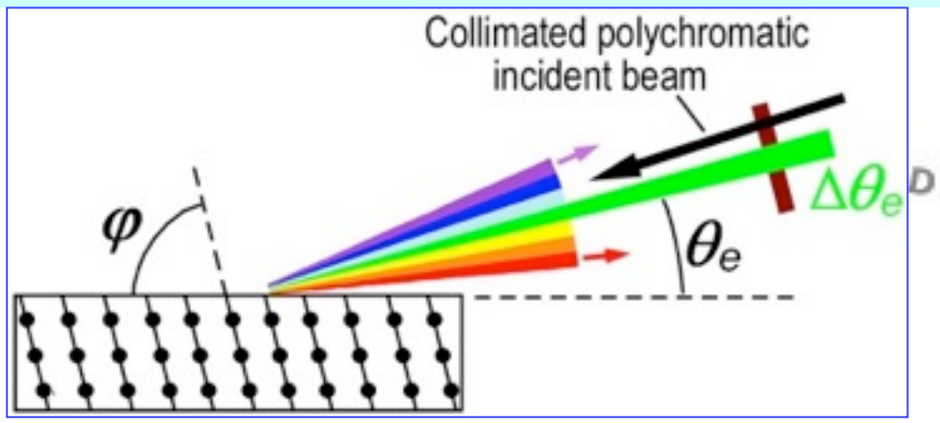
IXS: Scientific Interest, Technique

- Scientific interest: Liquids, disordered systems, biological systems and phonons.
- Inelastic X-ray scattering at 9.1 keV with $\Delta E<1$ meV (0.1 meV)
- High Beta, IVU22, 3.0 m
- Flux at sample > 10^9 photons/sec/1meV
- Q range / resolution: 0.1 ~ 40 nm^{-1} / ~ 0.1 nm^{-1}
- Focus: ~ < 5 µm (V) x 10 µm (H)

IXS: Beamline Layout



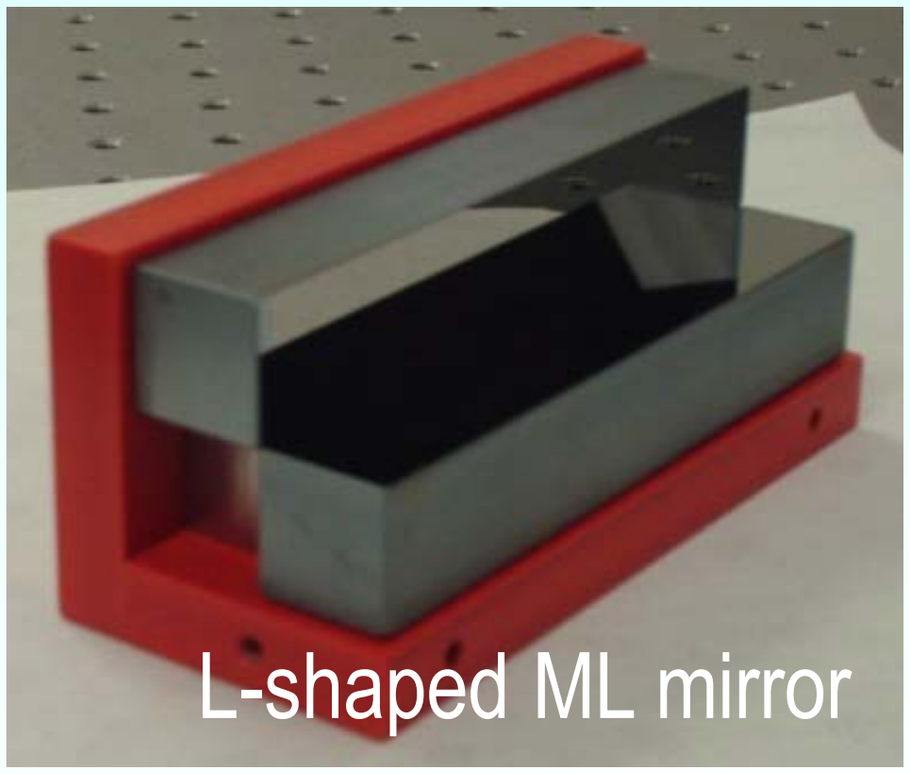




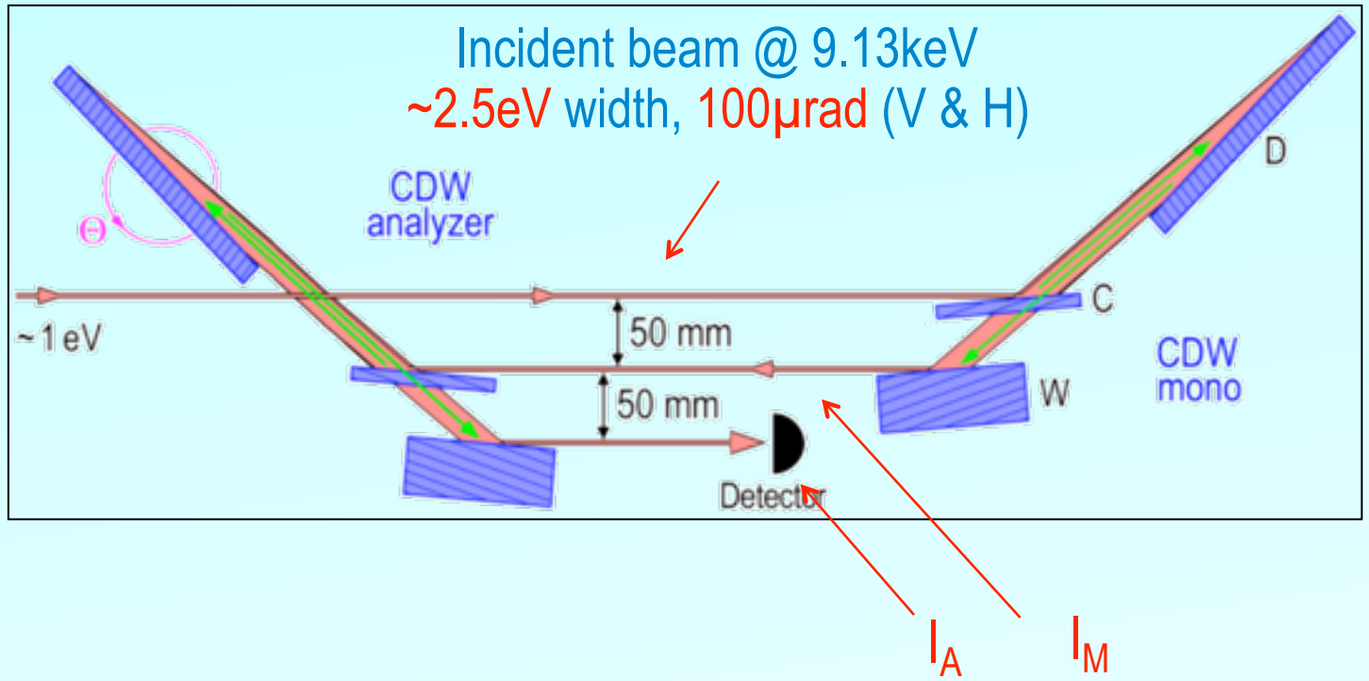
IXS Optics

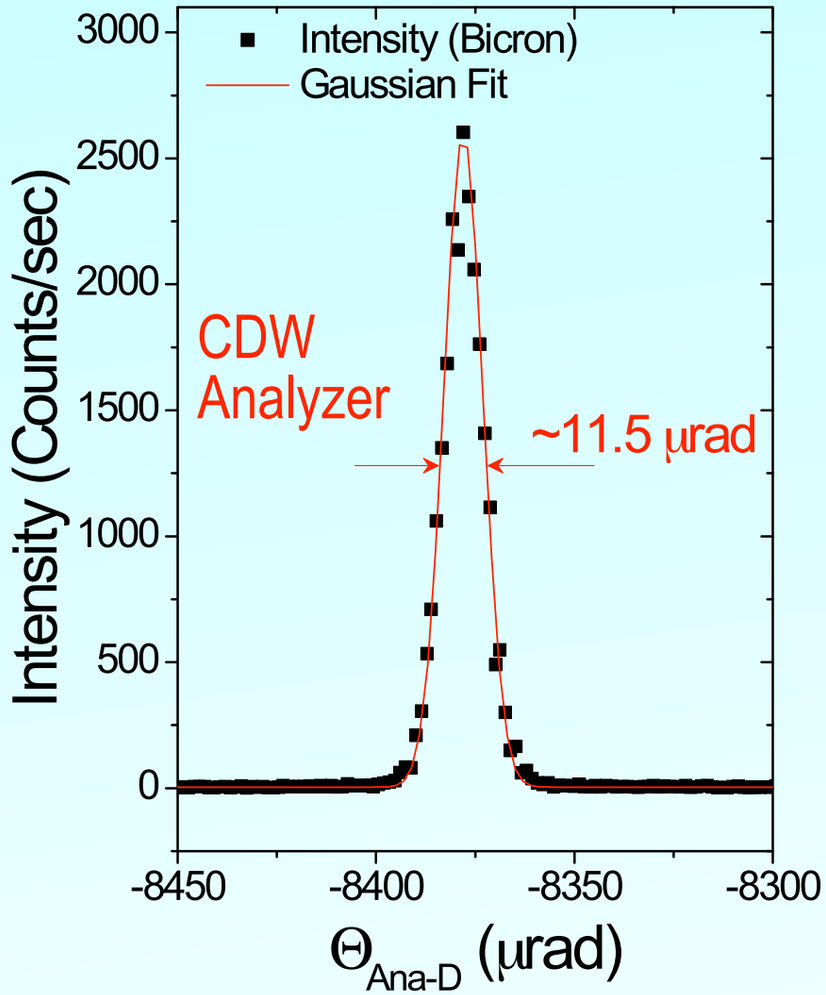
	Optical Size (mm)	Demag.	Angle (mrad)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
KBV: Elliptical Cylinder (Bender)	940	19:2	3.5	0.5	10	
KBH: Elliptical Cylinder (Bender)	780	57:1	3.5	0.5	5	$\approx 10^9$ /eV

- Montel with laterally graded W/Si
- Collects 10×10 $mrad^2$
- Collimates for CDDW detector to 0.1×0.1 $mrad^2$



Latest CDW-CDW Results from X16A

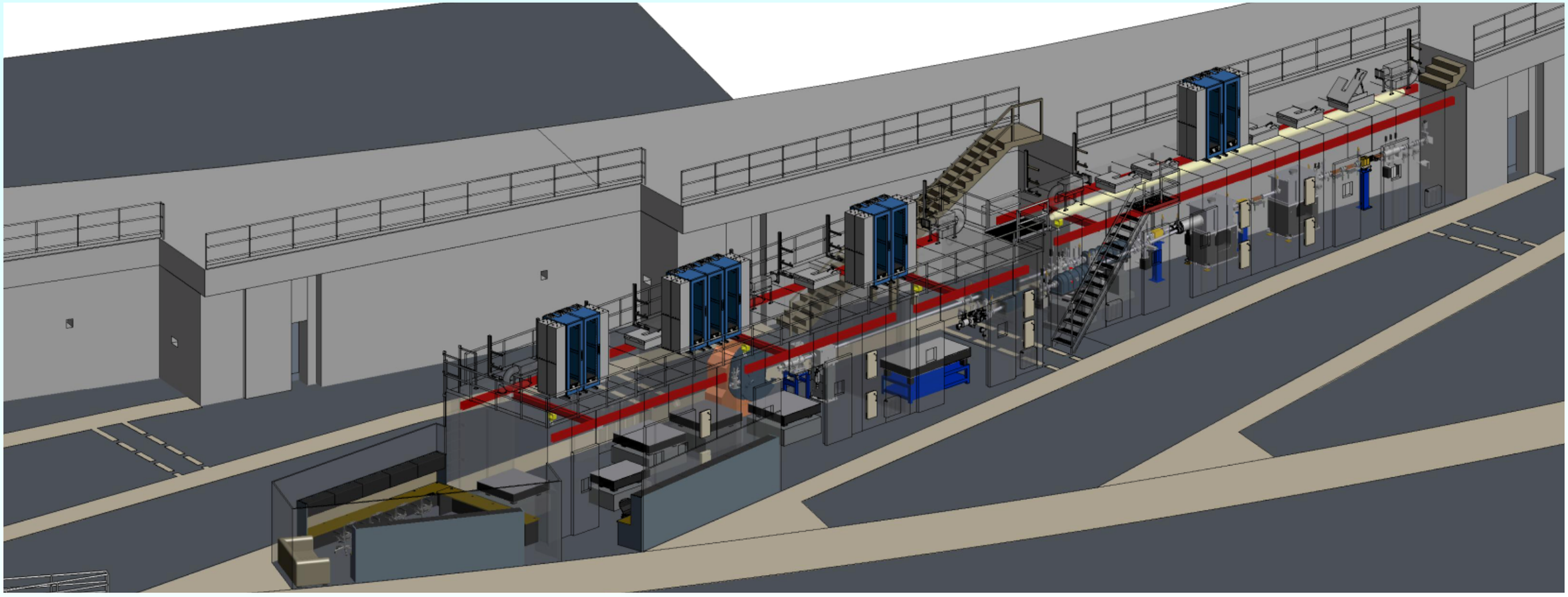




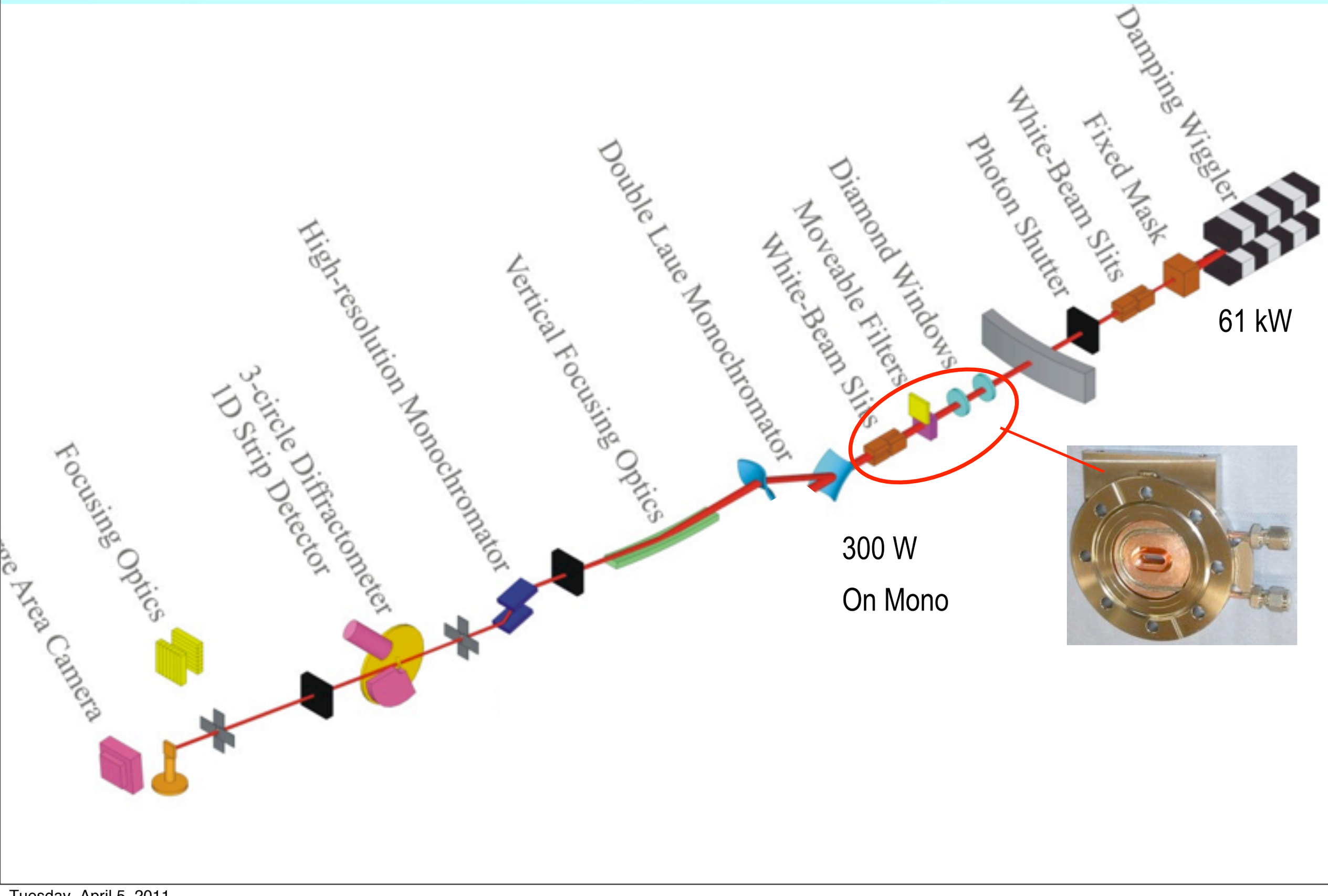
- Achieved energy resolution: ~ 2.6 meV with sharp tails
- Efficiency of one CDW unit: I_A/I_M > 1.5%

XPD: Scientific Interest, Technique

- Scientific interest: Powders and nanostructures, extreme environments, time-resolved and total scattering studies.
- 30-80 keV: Powder diffraction & WAXS
- High Beta, Damping wiggler, 100 mm period, 7 m long, 61 kW
- High flux at sample > 10^{12} ph/s in variable 0.5-2 mm focus
- Operation modes: $\Delta E/E \sim 10^{-3}$ (high flux) or 2×10^{-4} (high resolution)



XPD: Beamline Layout

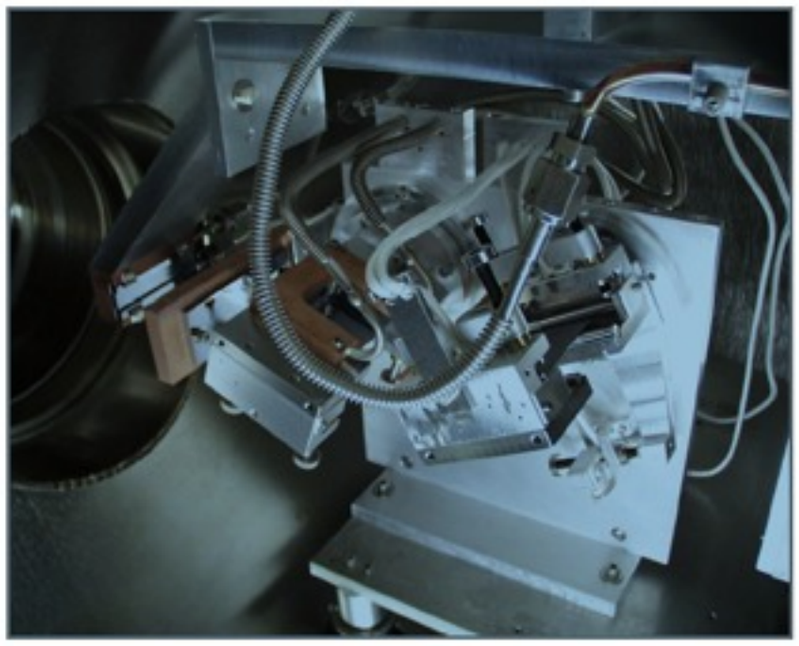


XPD Optics

	Optical Size (mm)	Demag.	Angle (mrad)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
Elliptical Cylinder - Flat	1300	40:14	1-2	1.2 (0.5)	55 1500	510^{12} (0.1%) 10^{12} (0.01%)

- Double Laue Monochromator (Zhong)
  - Energy tunability : 30 - 80 keV
  - Sagittal focusing 500μm
  - Beam stability under large thermal load

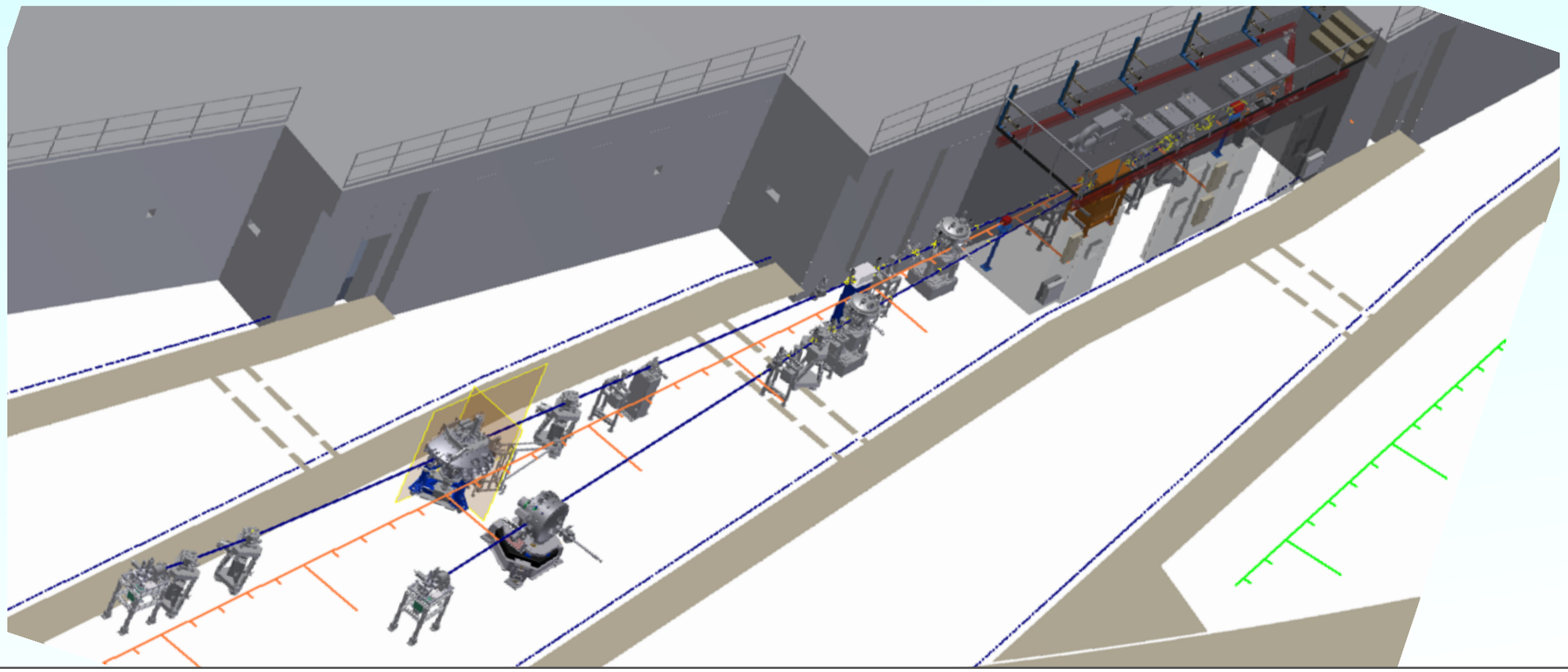
NSLS X17B1 Monochromator



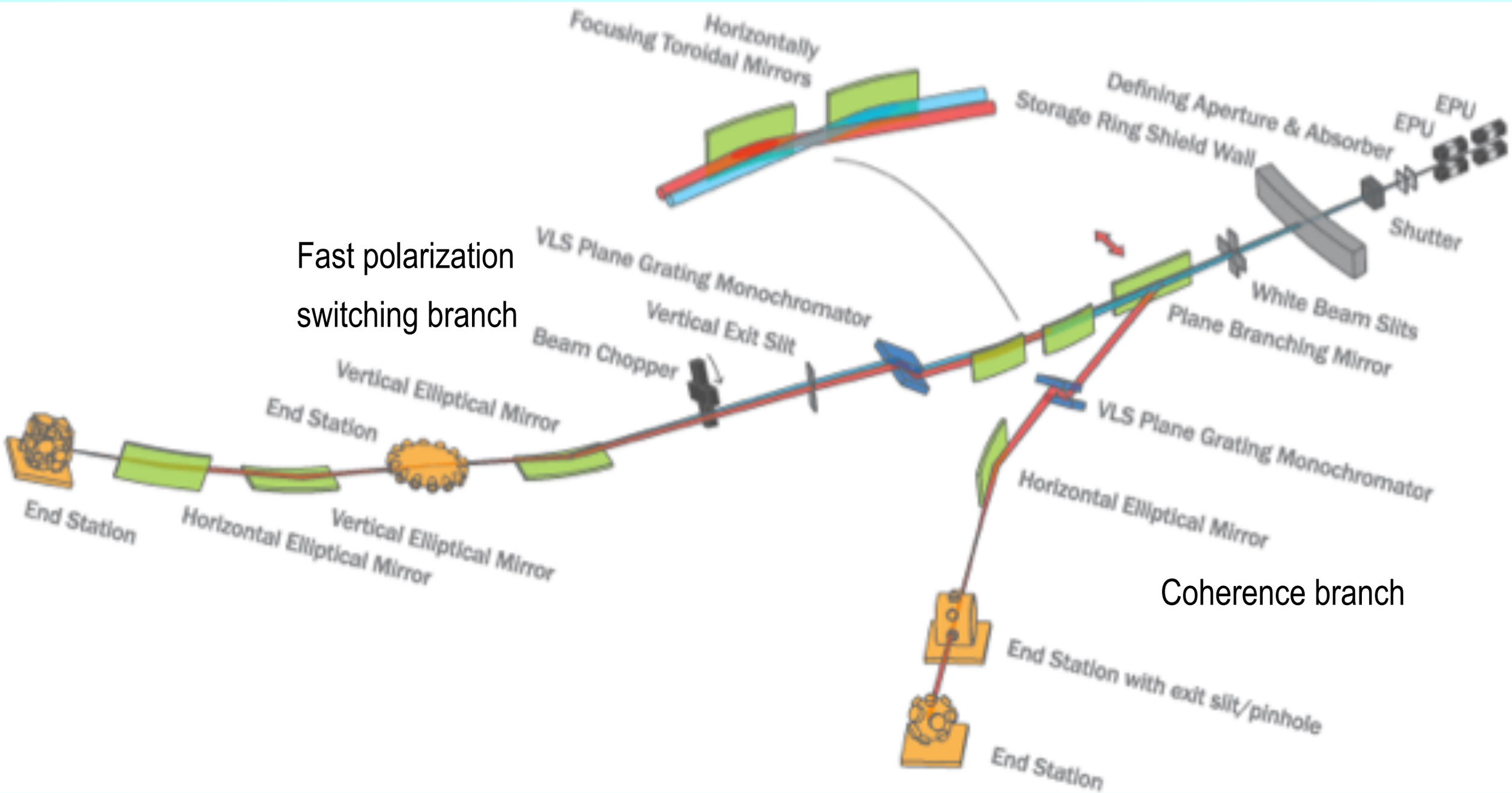
113 reflection, provided 10^{11} ph/s at 67 keV with a focal length of
5.6 meters. Focuses 40 mm-wide beam to 0.5 mm (horizontal)

CSX: Scientific Interest, Technique

- Scientific interest: Ferromagnets, strongly correlated systems, oxides, functional multilayers, soft matter, polymers, multifunctional materials, magnetic systems and fast magnetic dynamics
- Coherent diffraction/scattering, phase retrieval imaging, spectroscopy (XMCD), and magnetic scattering
- Low Beta, 2× APPLE II, 49 mm period, 2 m each. Canted or phased
- Flux PB: > 10^{13} photons/s/0.01% CB: >10^{13} photons/s/0.1%



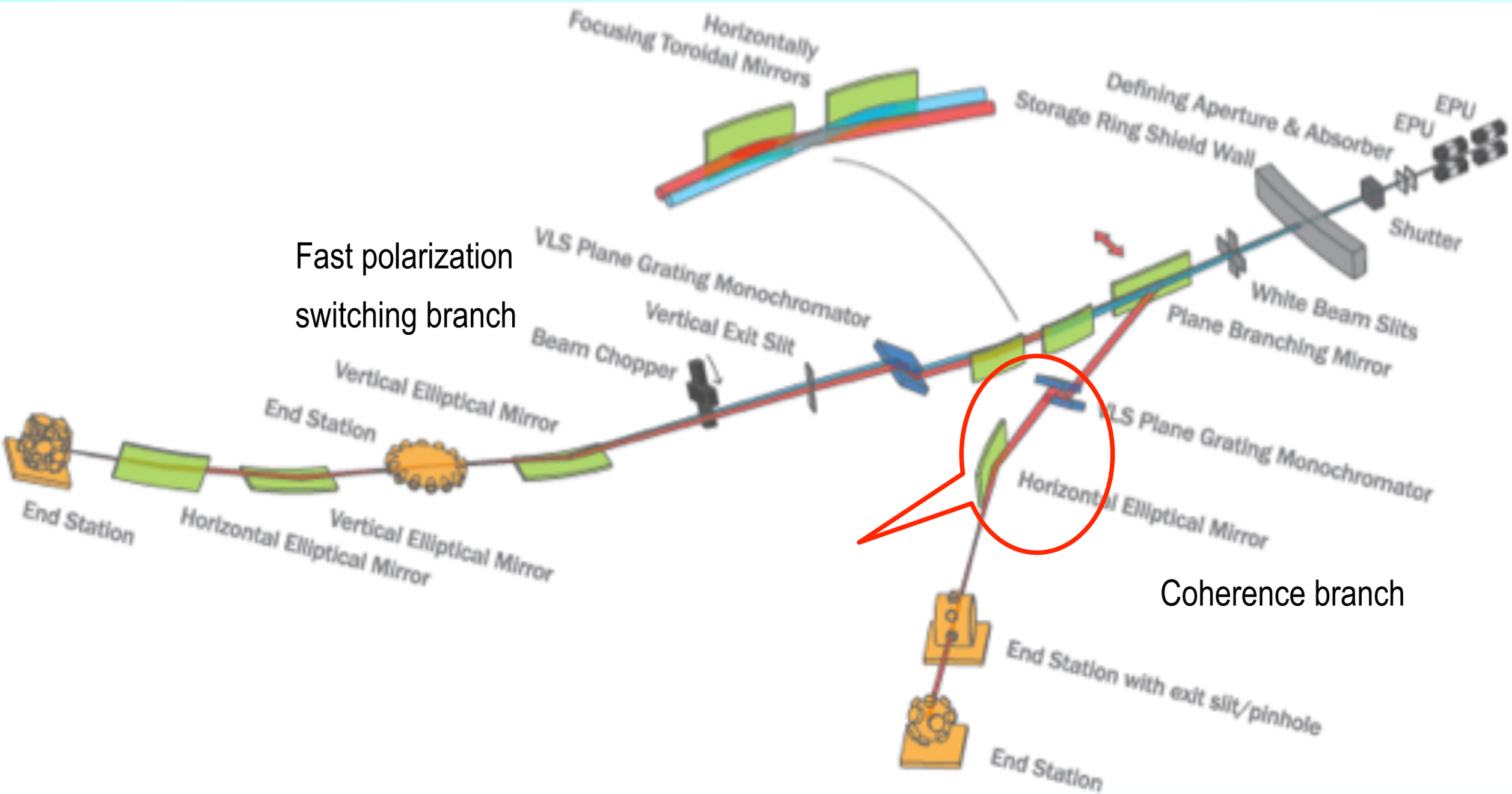
CSX: Beamline Layout



Fast polarization switching branch

Coherence branch

CSX: Beamline Layout



Fast polarization switching branch

Coherence branch

CSX Optics, FPB

	Optical Size (mm)	Demag.	Angle (deg)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
Toroid 1	250	33:21 33:∞	1.25	0.5 (1)	70 (hor.)	R,ρ±0.5%
Toroid 2	250	31:21 31:∞	1.25	0.5 (1)	70 (hor.)	
Plane in Mono	400		Var	0.2		
Gratings, VLS	120	32:7 (With c_{eff})	Var	0.1	18 (250eV) 13 (1keV)	
Spherical	150	3:3	1.25	0.3 (0.5)	8 (10μm slit)	10^{13} (10^4 RP)

CSX Optics, CB

	Optical Size (mm)	Demag.	Angle (deg)	SE RMS (μrad)	Size (μm)	Flux (Phot/s)
Plane	200		1.25	0.2		
Plane in Mono	400		Var	0.2		
Gratings, VLS	120	40:13±2 (with c_{eff})	Var	0.1	25 (200eV) 15 (1keV)	
Bendable Elliptical cylinder	300	41:13±2	1.25	0.3 (0.6)	30 (200eV) 28 (1keV)	10^{13} (RP 2000)

NEXT Beamlines (all ID based)

ESM: Electron Spectro-Microscopy (2 EPUs)

ARPES, PEEM, APP 20 eV-2 keV

SIX: Soft Inelastic X-ray Scattering

RIXS: 10 meV at 1 keV and medium resolution

ISS: Inner Shell Spectroscopy (DW)

XAS, XES, XELS

FXI: Full-field X-ray Imaging from µm to nm (SCW)

TXM, full field imaging

ISR: Integrated In-Situ & Resonant X-Ray Studies (IVU)

Resonant: x-ray scattering, x-ray diffraction, linear circular polarization

SMI: Soft Matter Interfaces (IVU)

x-ray reflectivity, GI x-ray scattering, and anomalous/resonance techniques

- CD1 Review September 2011
- Group leader positions will opening soon

NIH + Type II + Nxt Gen

- NIH + NSLS-II will develop 3 beamlines for life sciences
- Two NIST
  - SST: Soft and Tender X-ray Spectroscopy and Microscopy
    - 6 stations, 2 from 100 eV-7.5 keV
  - BMM: Hard X-ray Absorption Spectroscopy and Diffraction - Beamline for Materials Measurements
- NYSBC
  - NYX: Microdiffraction Beamline
- 14 beamlines to be transferred from NSLS

Status

- Halfway mark in project completion
- Beneficial occupancy of first pentant
- First girder assembly in the building
- SOW being written for the beamlines
- 2014 CD4 project beamlines
  - Project end

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Thank you for your attention

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES