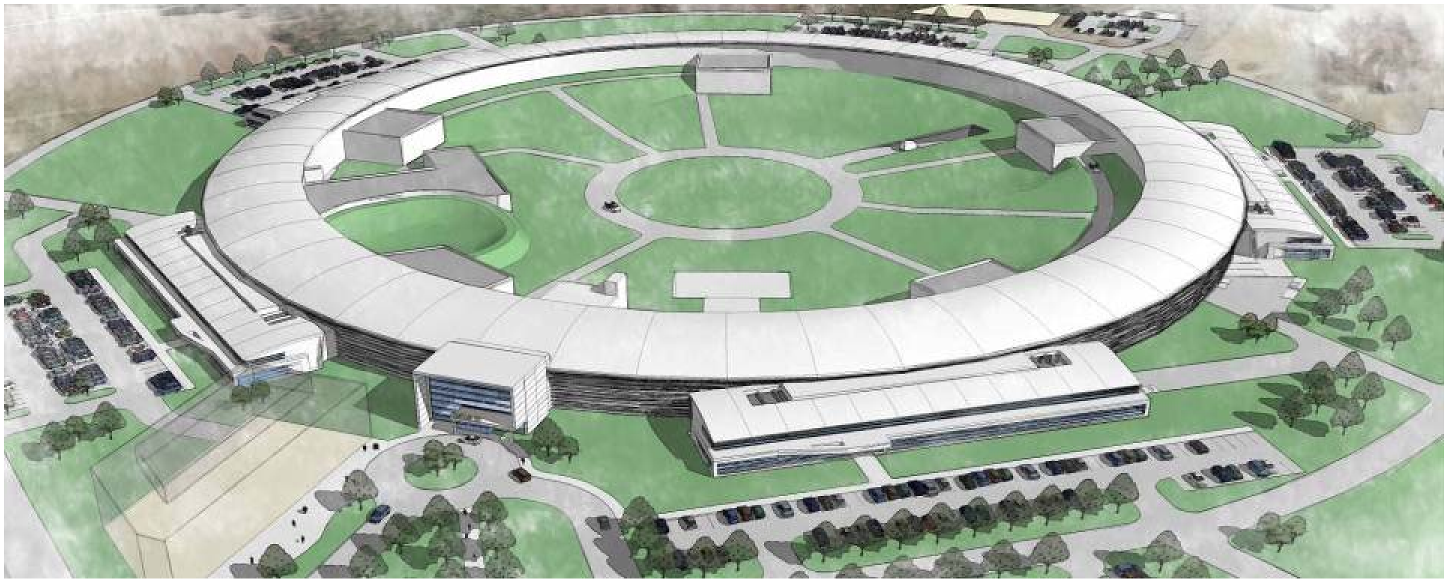
National Synchrotron Light Source II



Soft x-ray coherent scattering and imaging beamline

C. Sánchez-Hanke
October 4th, 2007

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Soft x-ray coherent scattering and imaging beamline

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[a]Brookhaven National Laboratory, Upton, NY
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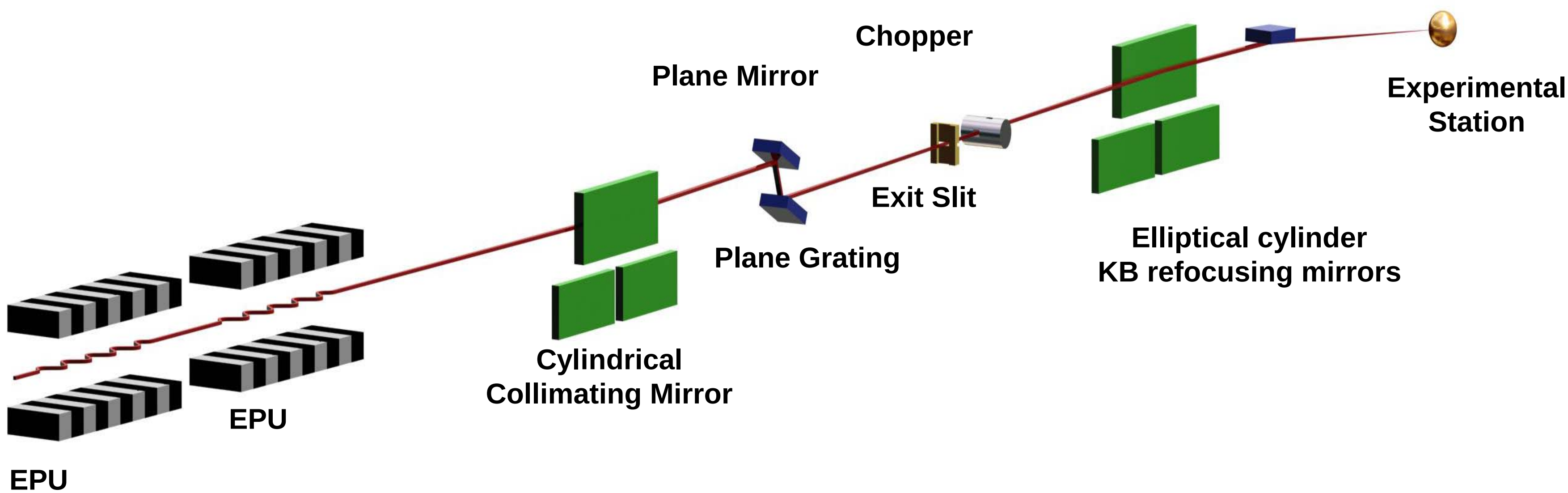
[c]Physical Sciences Laboratory, Stoughton, WI



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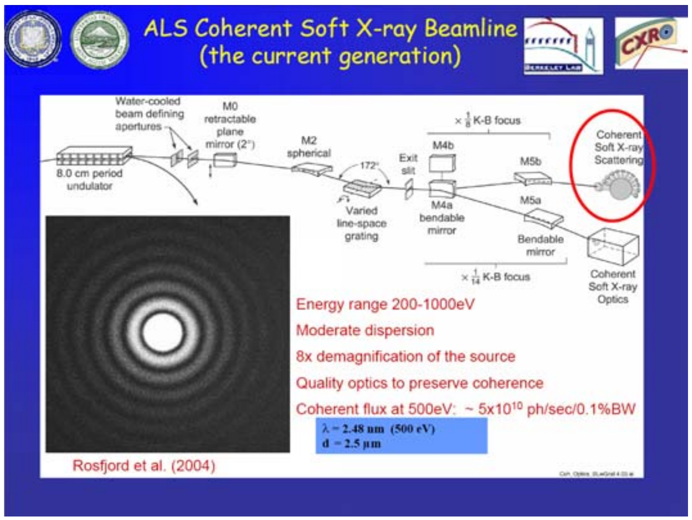
Scientific Mission

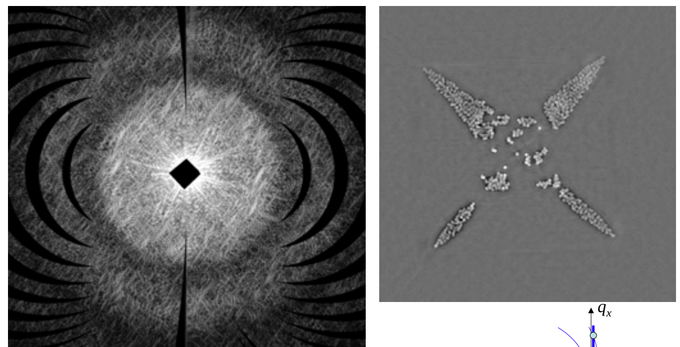
- Soft x-ray beamline design optimized for experiments demanding high photon flux
  - mesoscopic imaging, e. g. large cells and magnetic domains
  - time correlation spectroscopy; 3D imaging, e.g. of granular (~30nm) materials
  - ordering phenomena in correlated electron systems, magnetic and spintronic materials/devices
  - nanomagnetism, “soft” materials (C, N, O)
  - simultaneous spectroscopic (electronic) and microscopic (structural) measurements on nano- and mesoscopic length scales, e.g. of single nano-elements, nano-contacts, or nano-magnets, to understand isolated behavior differences between boundaries/interfaces and bulk
- Wide variety of applicable soft x-ray techniques
  - Diffraction/scattering
  - SAXS, diffraction imaging, holography
  - STXM, phase contrast microscopy
  - full field microscopy
  - PEEM
  - spectro-microscopy

Scientific Mission

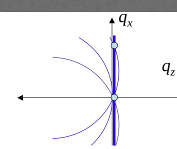
- Workshop July 18, 2007, 58 registered 25 attendees
  - talks: coherent scattering, STXM, diffraction microscopy , phase microscopy, and soft x-ray diffraction

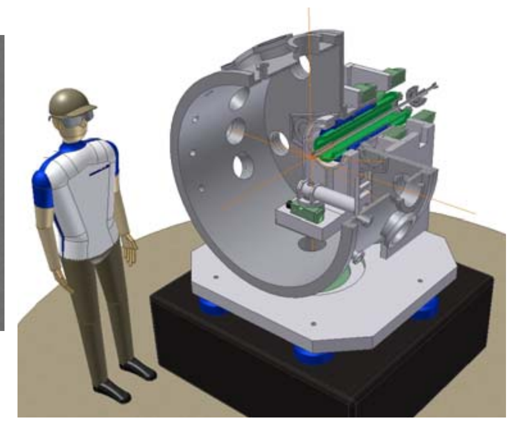


Experimental realization



Chapman, Barty, Marchesini, Noy, Hau-Riege, Cui, Howells, Rosen, He, Spence, Weierstall, Beetz, Jacobsen, Shapiro, *J. Opt. Soc. Am. A* **23**, 1179 (2006)

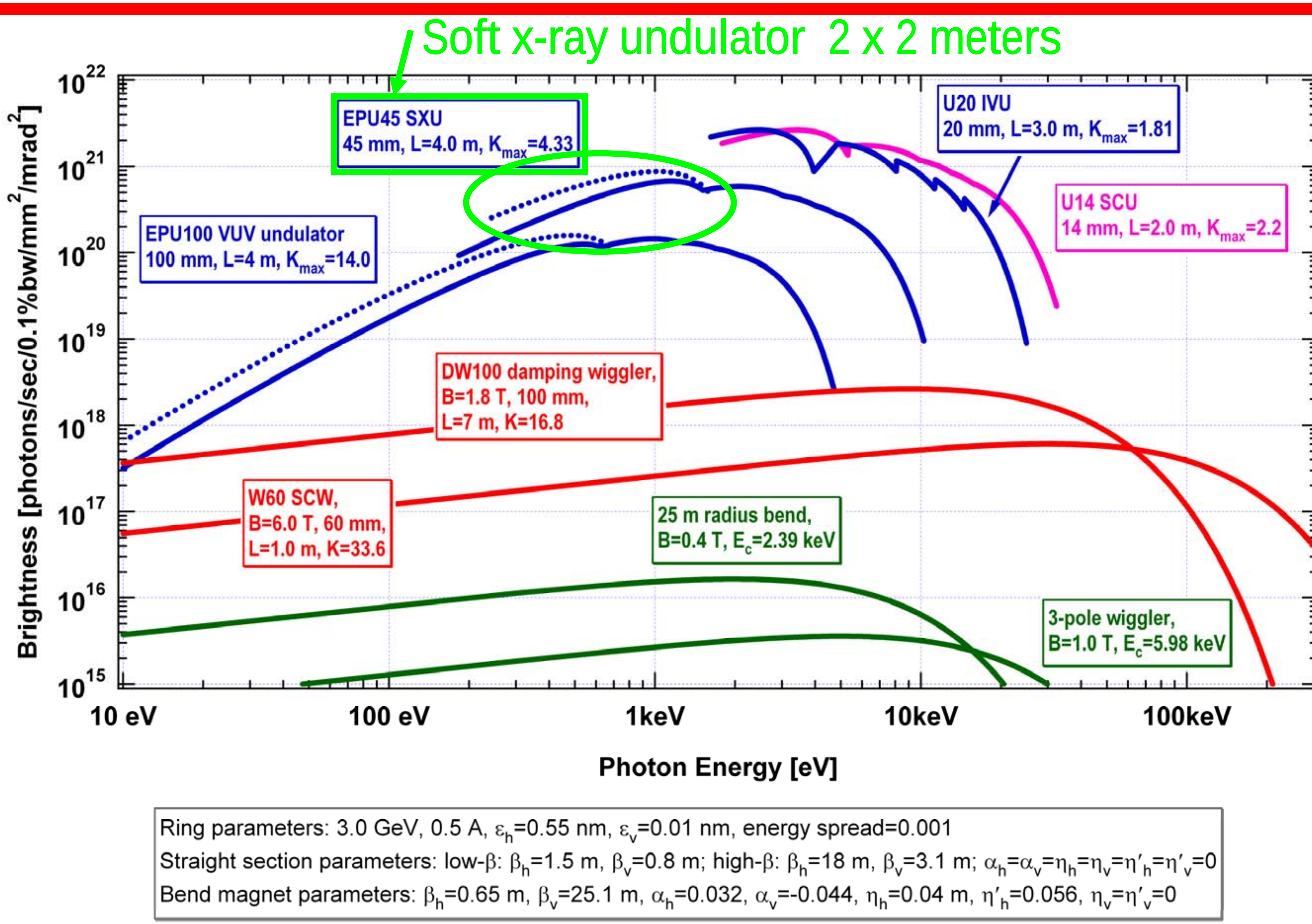




S. Kevan   C.Jacobsen   S. Wilkins

- Workshop to be held ~January 2008: form BAT(s)

Soft x-ray undulator: brightness

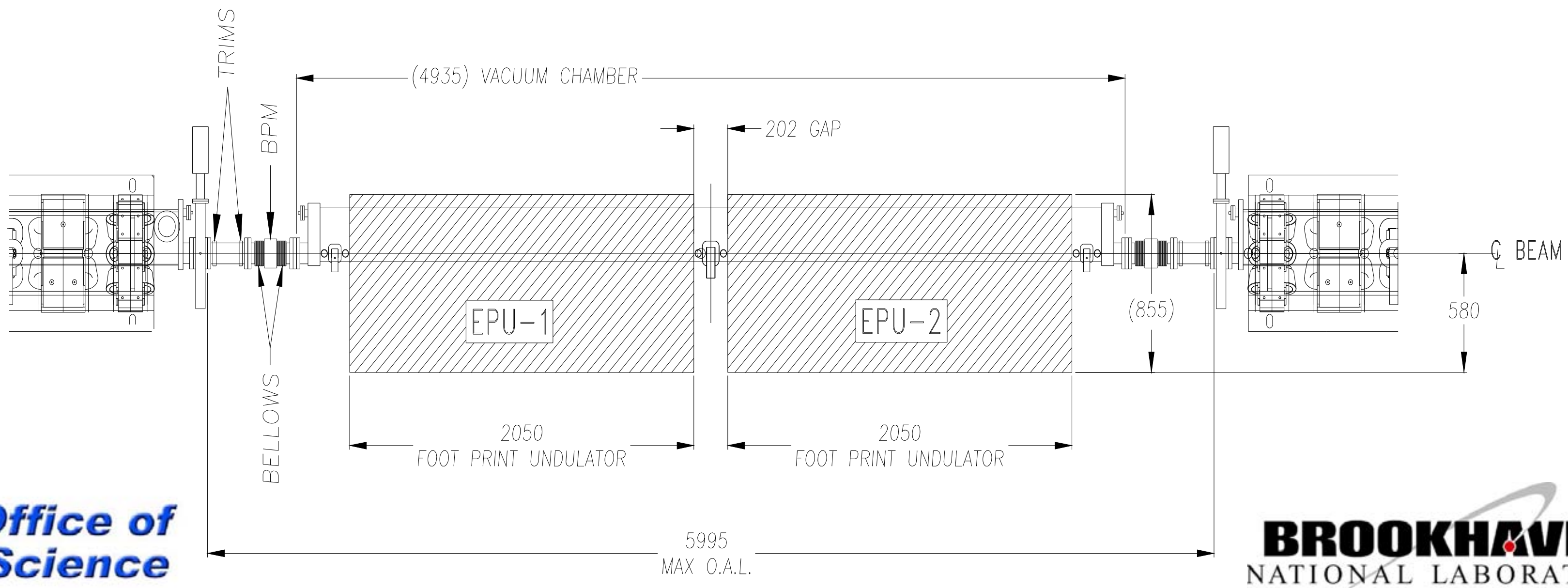


Beamline Specifications and Requirements

- Specifications
  - 200 to 2000 eV energy range
  - circular and linear polarization with fast-switching capability
  - spot size on sample: ~4 μm x ~4 μm (4-σ)
  - >95% overlap of the two polarized beams on sample
  - Flux: 10^{12} - 2 x 10^{13} photons/sec depending on energy resolution
- Requirements
  - Ultra-stable electron beam to provide constant polarization ratio
  - Exceptional intensity stability, which requires ultra-stable electron beam and beamline components. Especially true for microscopy applications (requires 1 part in 10^5 intensity stability on sample, or beyond state-of-the-art I_0 normalization)

Insertion Devices

- 2 x EPUs (APPLE II) canted by 0.16 mrad (horizontal plane)
  - Number of periods 44 } Length: 2m
  - Period length 45 mm
  - K_{max} 4.33 (linear mode), 2.69 (circular mode)
- Low-β straight section
- Need space for 2 insertion devices plus 3 canting magnets



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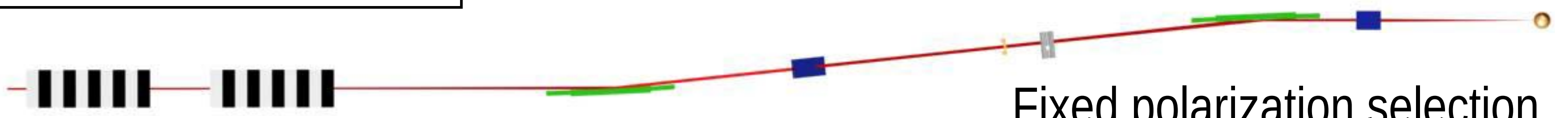
Beamline design: polarization switching using static canted EPUs

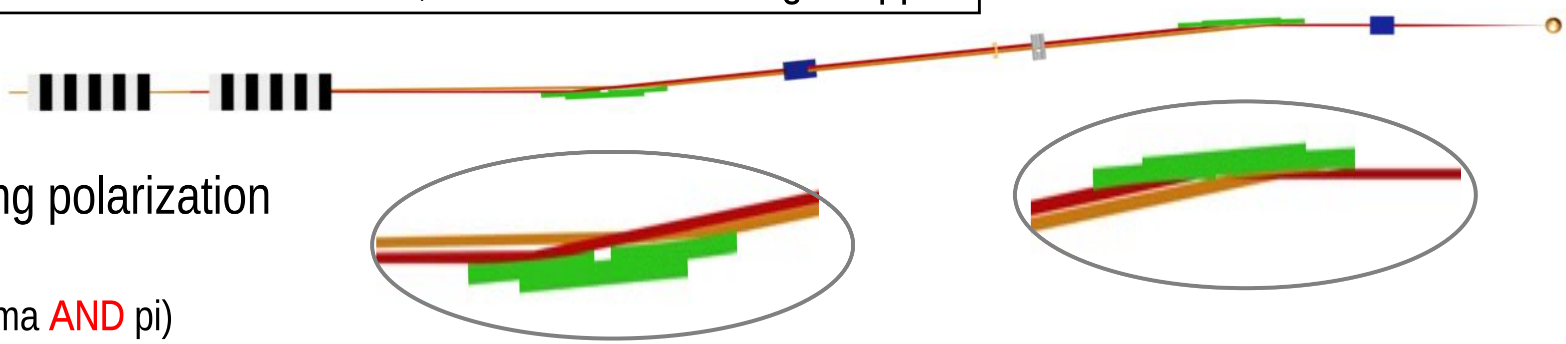
Top view, single beam mode



Fixed polarization selection

- Linear (sigma OR pi)
- Circular (left OR right)

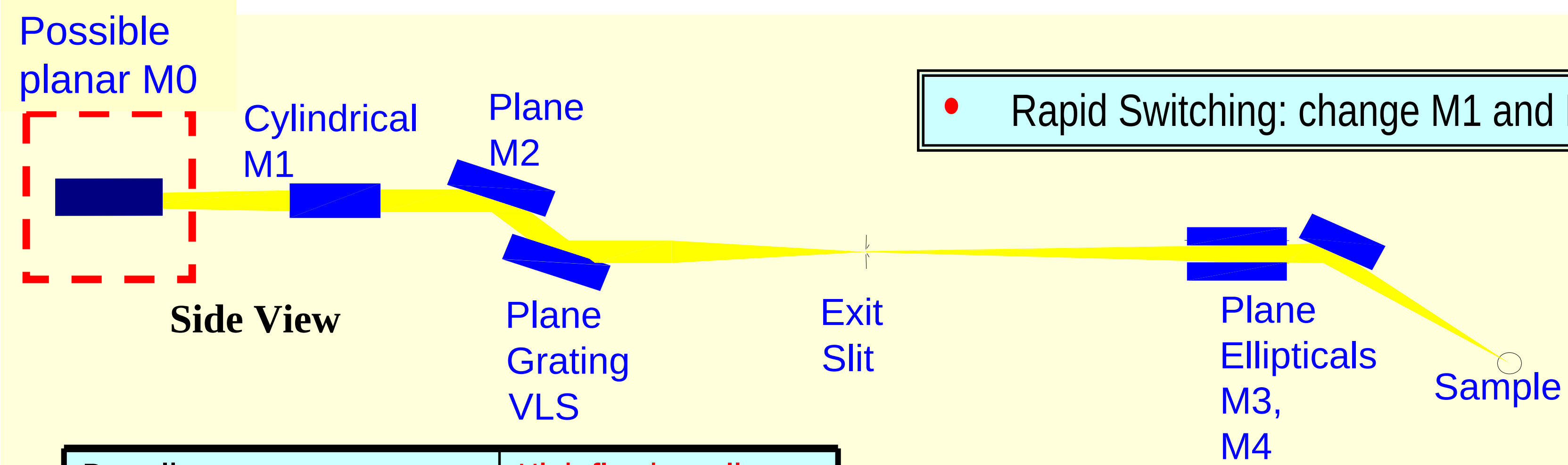
Top view, static canted beam mode, fast switchable using chopper



Fast-switching polarization selection

- Linear (sigma AND pi)
- Circular (left AND right)

Soft x-ray beamline optics design: VLS PGM illuminated by collimated light



- Rapid Switching: change M1 and M3

Beamline	High flux beamline short line
Source to M1	29.5 m
M0 to M1	~ 1 m ???
M1 to M2	2.19 m
M1 to grating	~3 m
Grating to exit slit	~10m
Exit slit to M3	~1.20m
M3 to M4	0.75m
M4 to sample	1.0m
Total	~45.00m

- Horizontal Focusing by M4 -- ~52:1

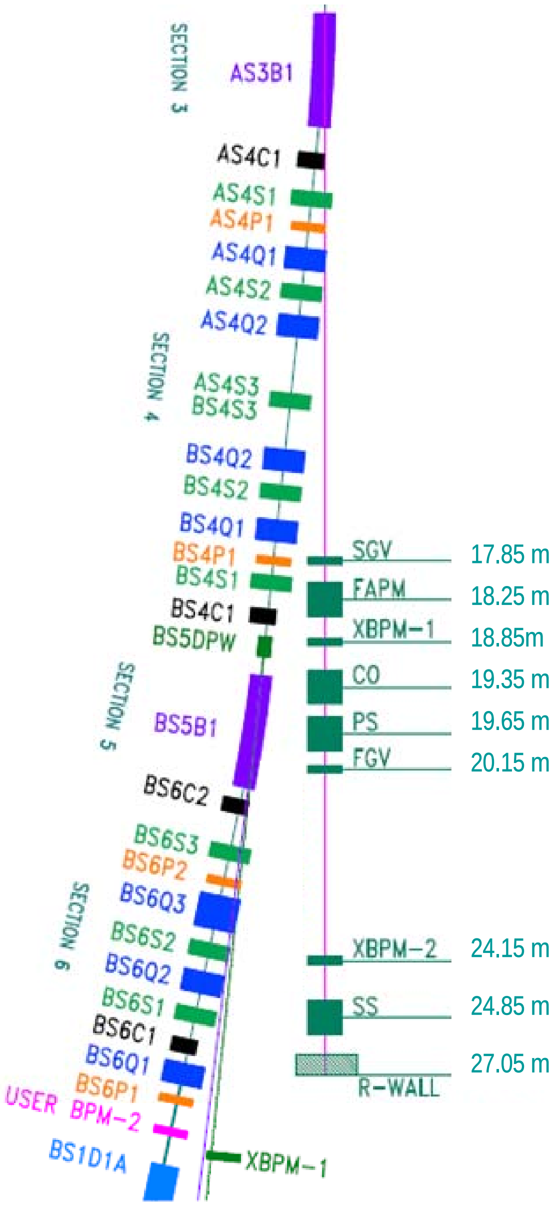
Effective source sizes @ $h\upsilon = 200\text{eV}$,

$L = 4\text{m}\,(2\,\text{m})$

$\Sigma_x = 54\,(47)\,\mu\text{m}, \Sigma_y = 35\,(25)\,\mu\text{m}$

$\Sigma_{x'} = 32\,(42)\,\mu\text{rad}, \Sigma_{y'} = 28\,(39)\,\mu\text{rad}$

Front end Layout



Non-standard items needed:

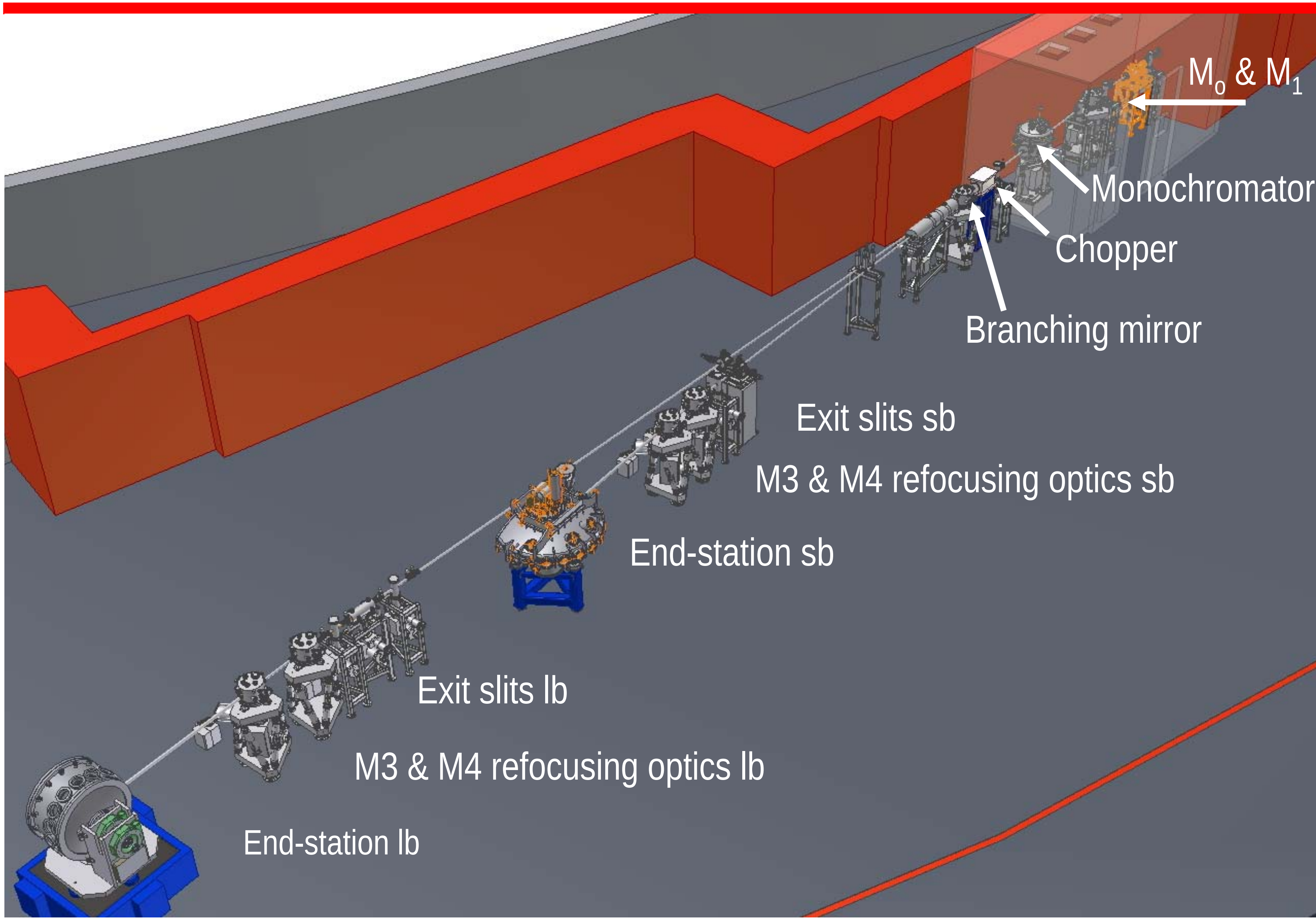
- Adjustable white beam apertures

Items not needed:

- No need for differential pumping section (windowless, ultra-high vacuum beamline)

SGV - slow gate valve
FAPM - Fixed aperture mask
XBPM - photon BPM (non-absorbing)
CO - lead collimator
PS - photon shutter
SS - safety shutter

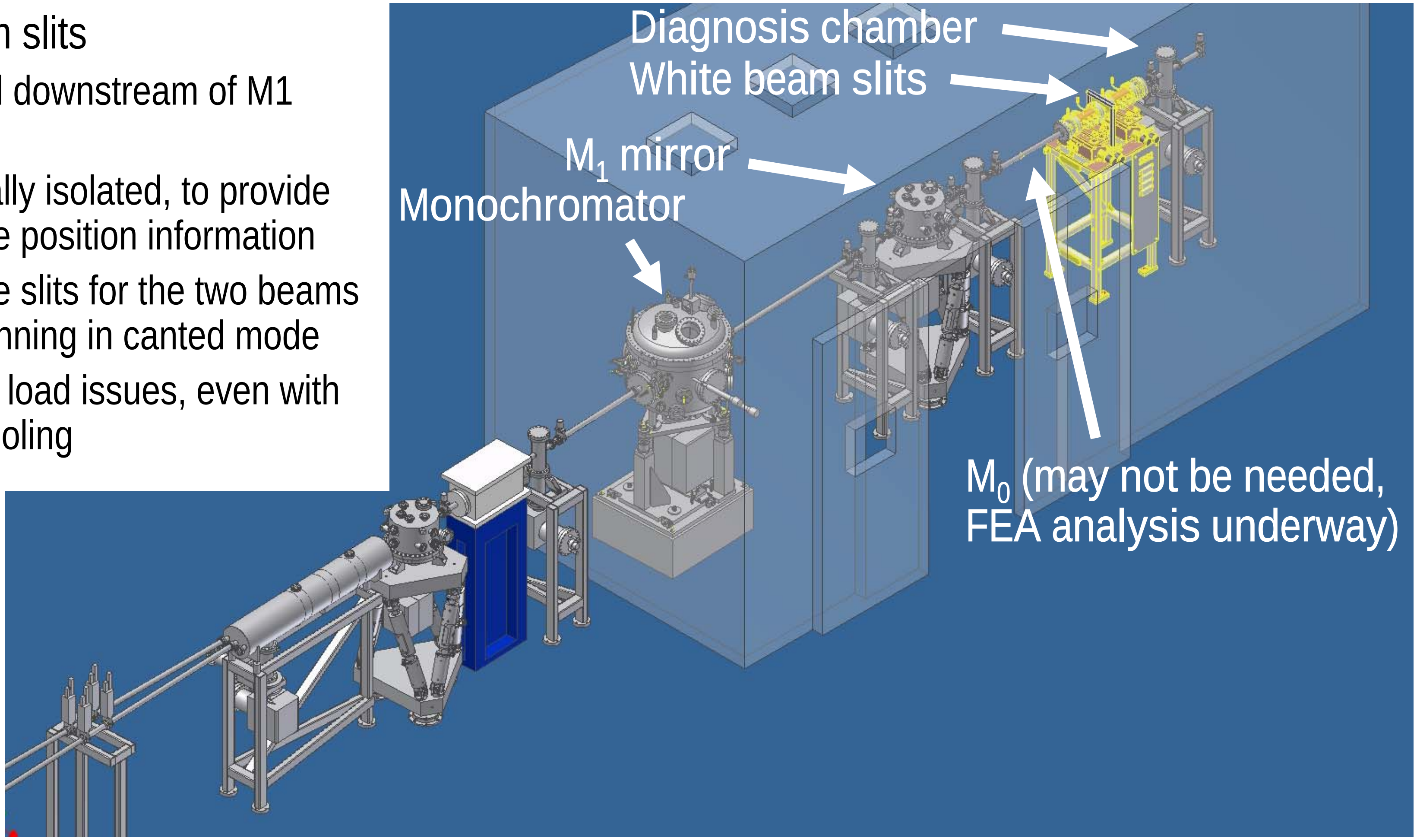
Soft x-ray beamline with two endstations



White Beam Components

White beam slits

- Located downstream of M1 mirror
- Electrically isolated, to provide beamline position information
- Separate slits for the two beams when running in canted mode
- Thermal load issues, even with water cooling



Beamline performance depends strongly on mirror and grating slope errors

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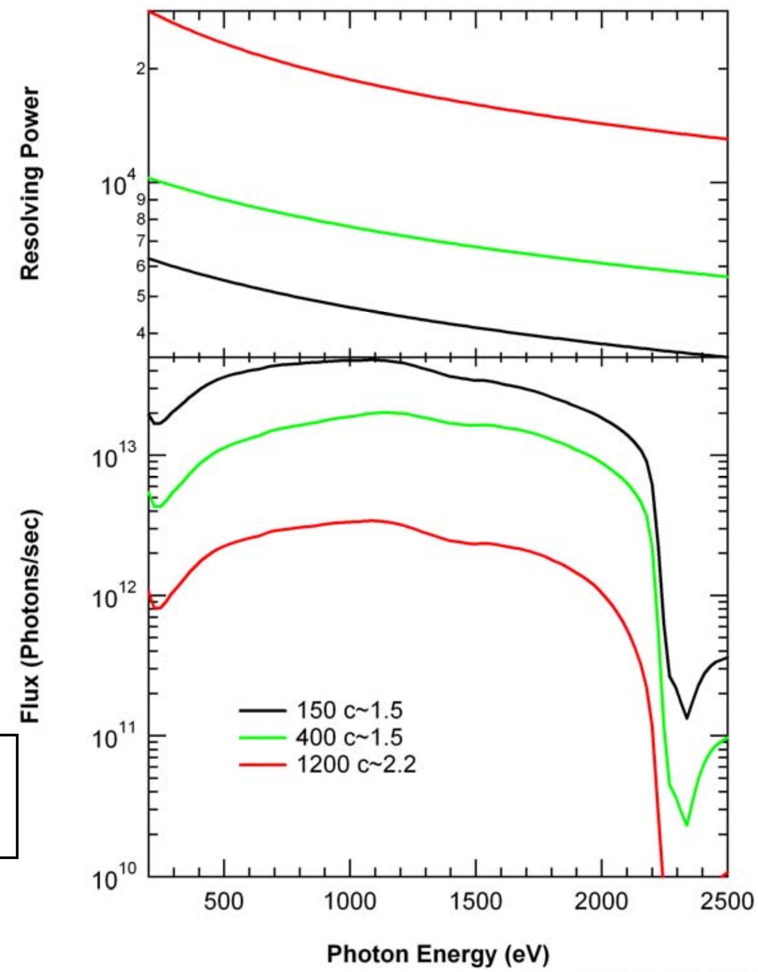
High flux monochromator

- Three-grating instrument
  - VLS PGM design
  - Vertical diffraction geometry is orthogonal to horizontal polarization separation → polarization components have same photon energy
  - High precision exit slit (10 μm minimum opening) located 10m downstream of mono (high dispersion)

High flux at medium to high resolution
10^{12}'s @ 2×10^4 rp; 10^{13}'s @ 5×10^3 rp

Calculated beamline flux and resolving power



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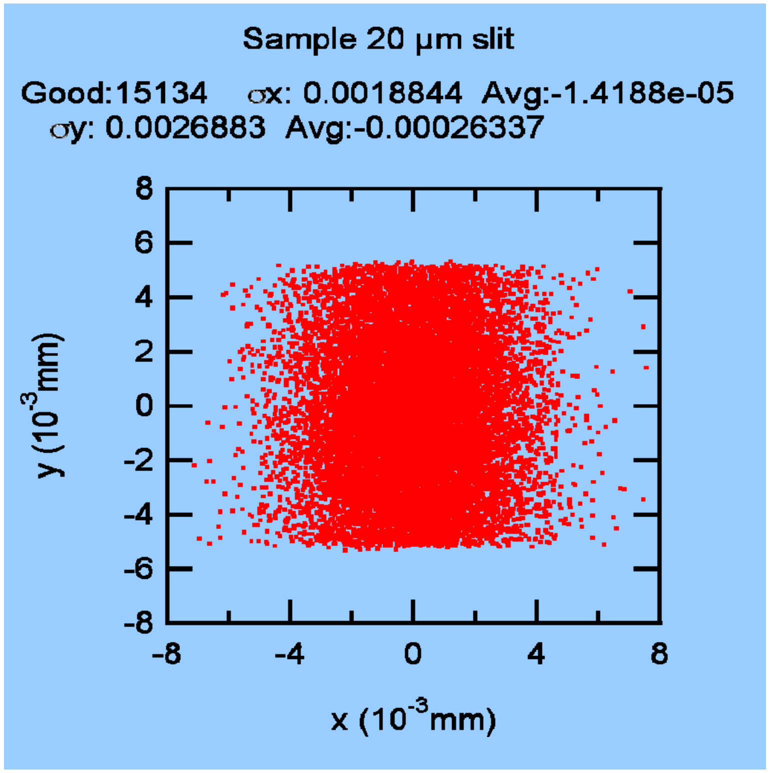
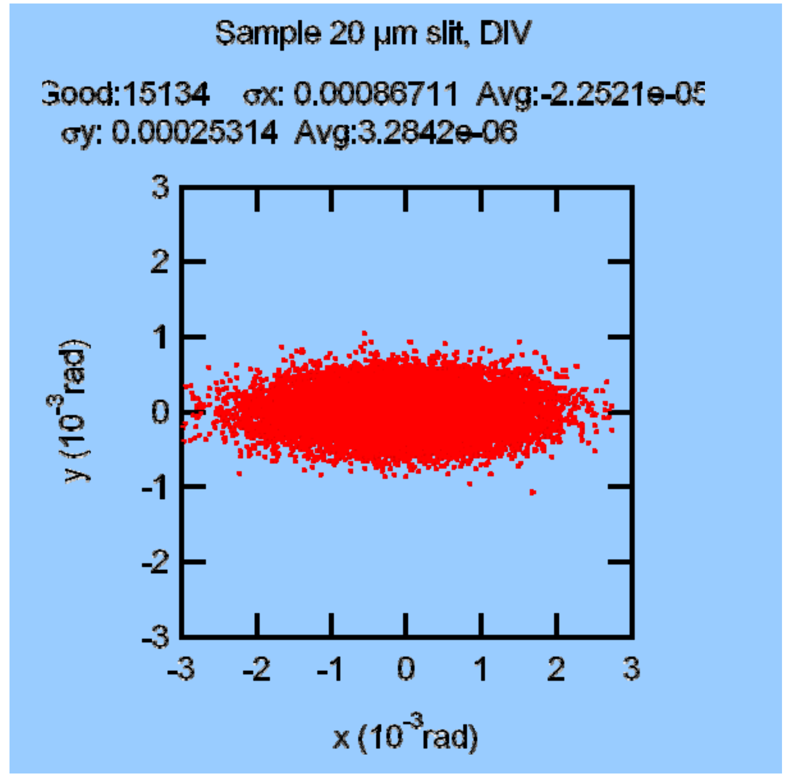
Divergence and spot size for single beam





$h\nu$=183eV: σ_h=1.88μm, σ_v=2.7μm **$h\nu$=183eV: σ_h=0.86mrad, σ_v=0.25mrad**

Req'd figure error →

- 100nrad RMS planes
- 0.5μrad RMS Elliptical, cylinder meridional

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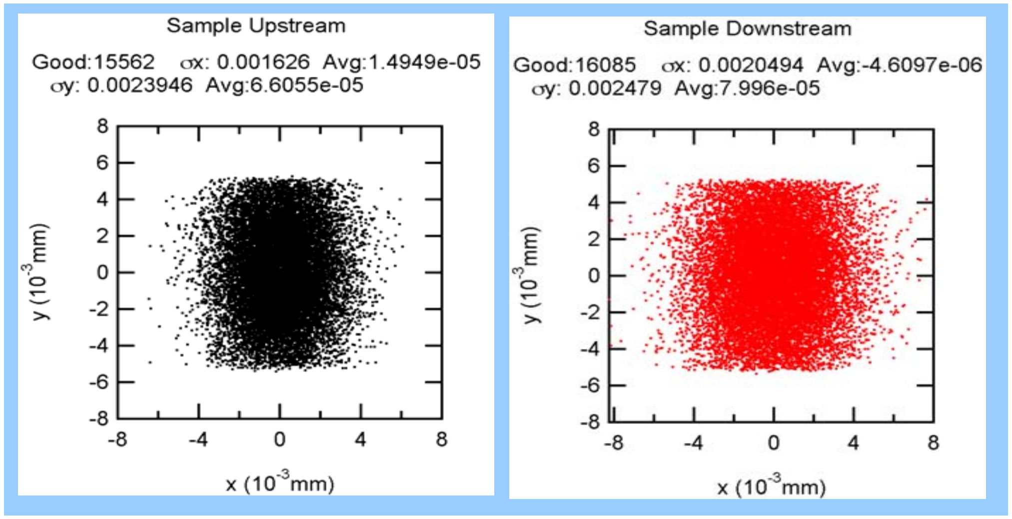
Spot sizes on sample, canted undulator beams

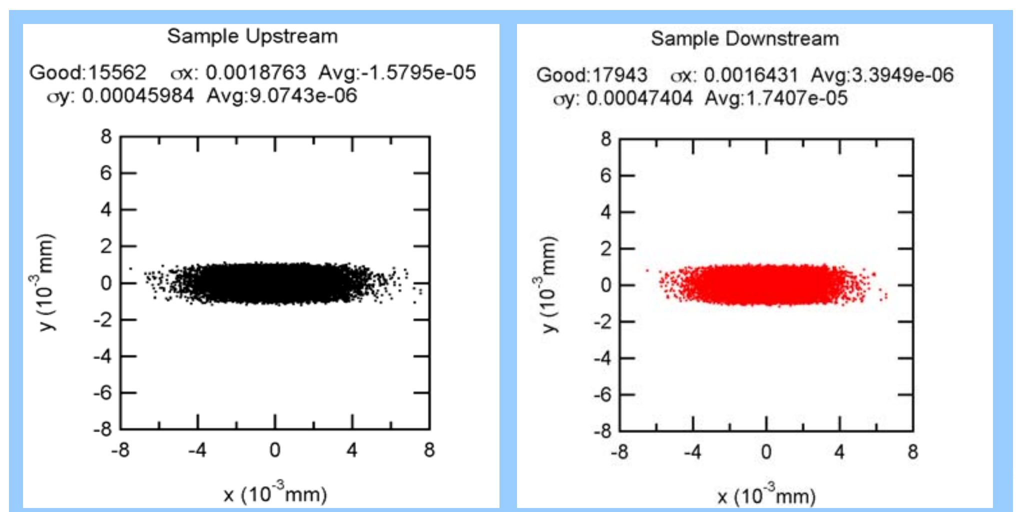
Sample spot on short branch



hν=183 eV: σ_h=1.6μm, σ_v=2.4μm

hν=183 eV: σ_h=2.0μm, σ_v=2.5μm

Sample spot on long branch



hν=183 eV: σ_h=1.8μm, σ_v=0.46μm

hν=183 eV: σ_h=1.6μm, σ_v=0.47μm

Soft x-ray beamline performance comparison

Beam Line Comparison	ALS 4.0.1	ALS 4.0.2	ALS 7.0.1	ALS 8.0.1	ALS 11.0.2	APS 4-ID-C	NSLS-II Soft x-ray	NSLS-II Soft x-ray
	(MERLIN)	(Mag. Spect)	(Elec. Struct. Fact.)	(RIXS, SXF)	(Molec. Env. Sci.)	(XOR-Polarization)	High Res.	High Flux
Energy Range (eV)	10 - 130	52 - 1900	60 - 1200	65 - 1400	75 - 2160	500 - 2800	200 - 2200	200 - 2200
Flux (photons/s/0.01%BW)	6 * 10^12	1 * 10^12	~10^12	10^11	~1 * 10^12	~ 1*10^11	5 * 10^10	2 * 10^13
@ hv = ??? eV	100	800			700	1000	1000	1000
Resolving Power	7 * 10^4	5,000-10,000	< 8,000	< 8,000	7500	~10^4	~10^5	~9000
@ hv = ??? eV	100							
Spot size @ sample, v x h (μm)	3 x 40 (1σ)	~100 x 1000	50 x ???	(50 --> 3000) x 100	2.5 x 4.7 (1σ)	~100 x 100	1.5 x 3 (1σ)	1.5 x 3 (1σ)

Polarized sources: ALS 4.0.2, APS 4-ID-C, NSLS-II soft x-ray

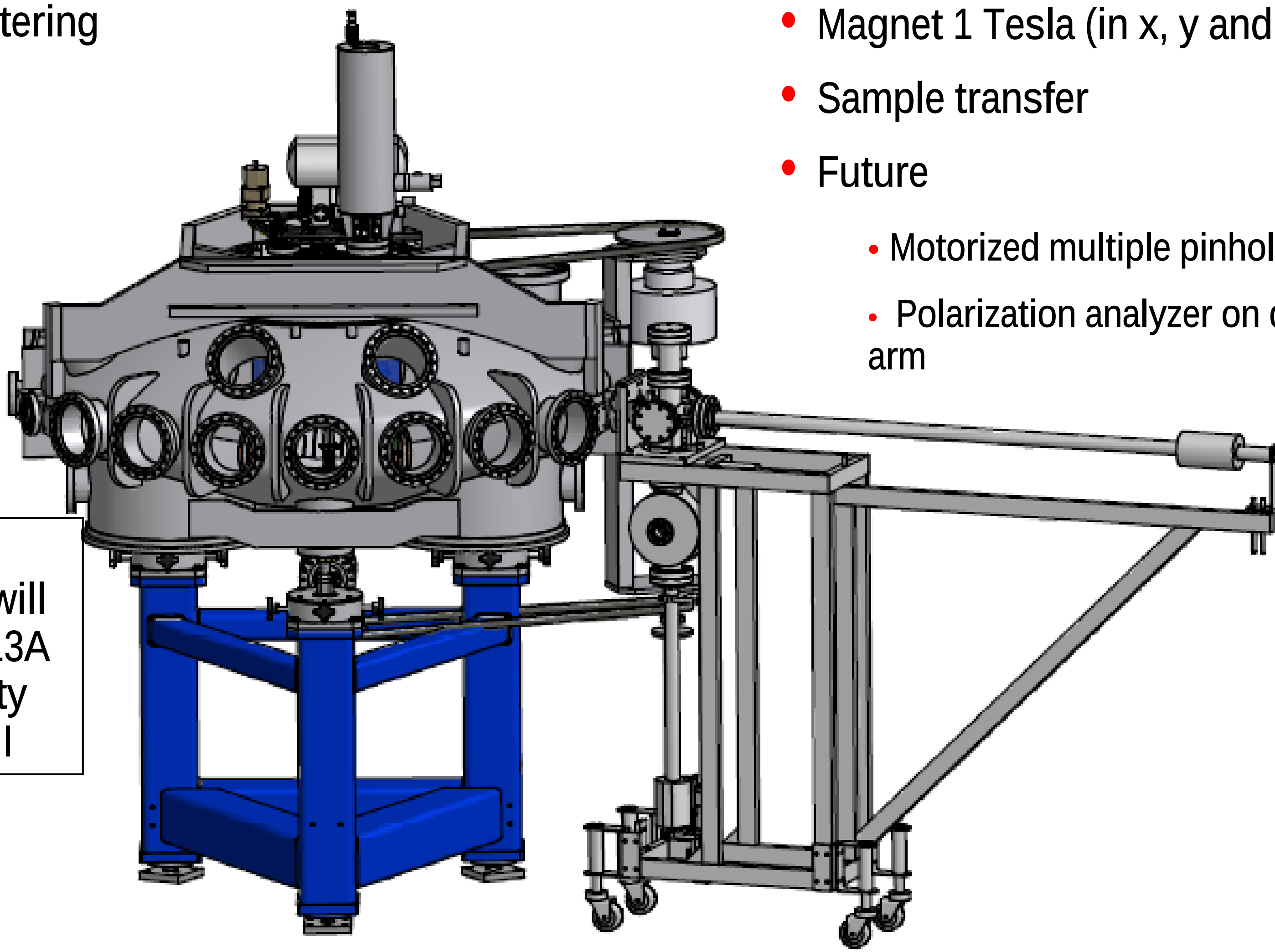
Endstation 1

Techniques

- Magnetic resonant scattering
- Coherent scattering
- Spectroscopy

Experimental capabilities

- Diffraction/scattering experiments
- Magnet 1 Tesla (in x, y and z)
- Sample transfer
- Future
  - Motorized multiple pinhole holder
  - Polarization analyzer on detector arm



Under construction; will serve NSLS X13A user community prior to NSLS-II

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Endstation 2

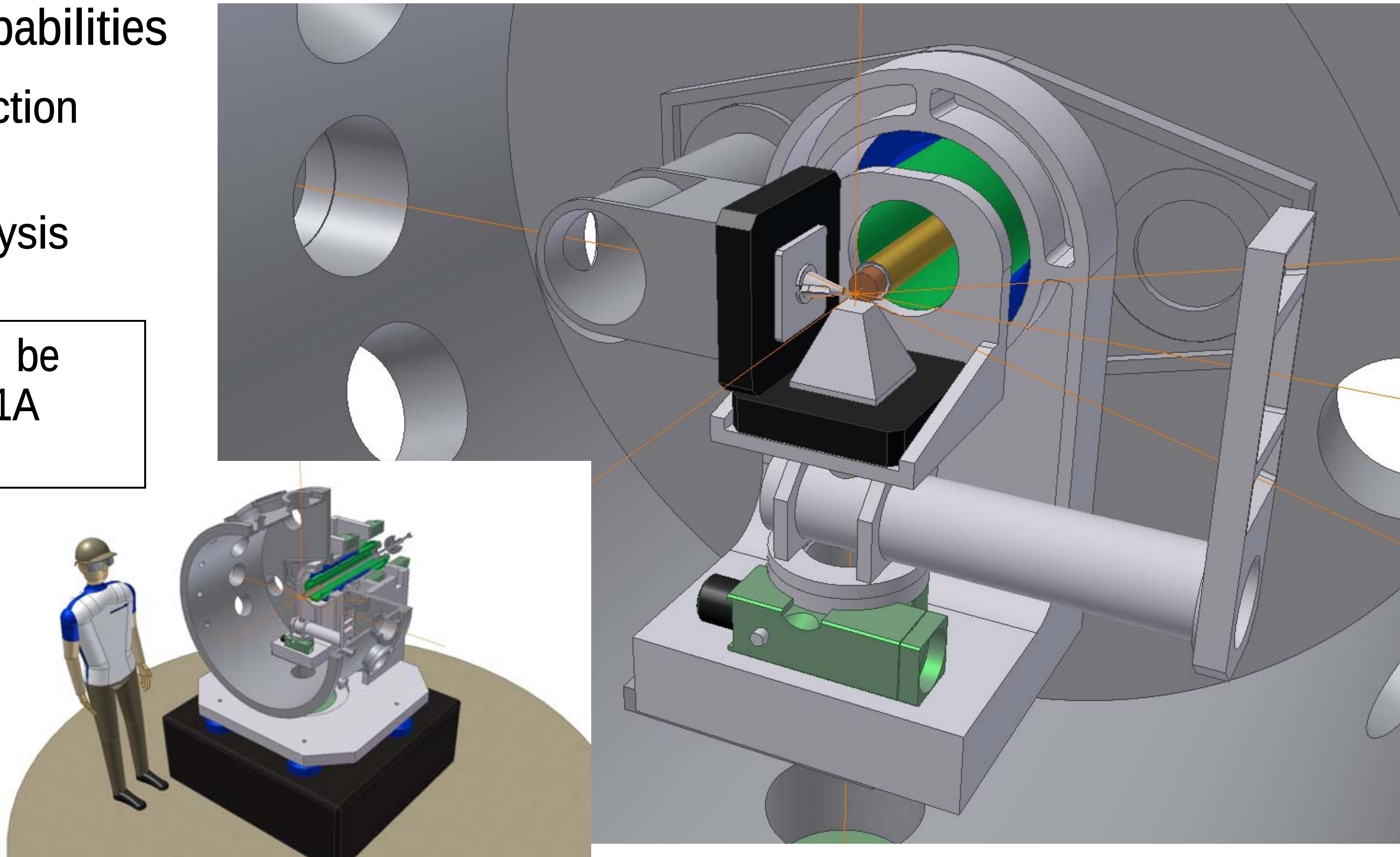
Technique

- Soft X-ray Diffraction Microscopy

Experimental capabilities

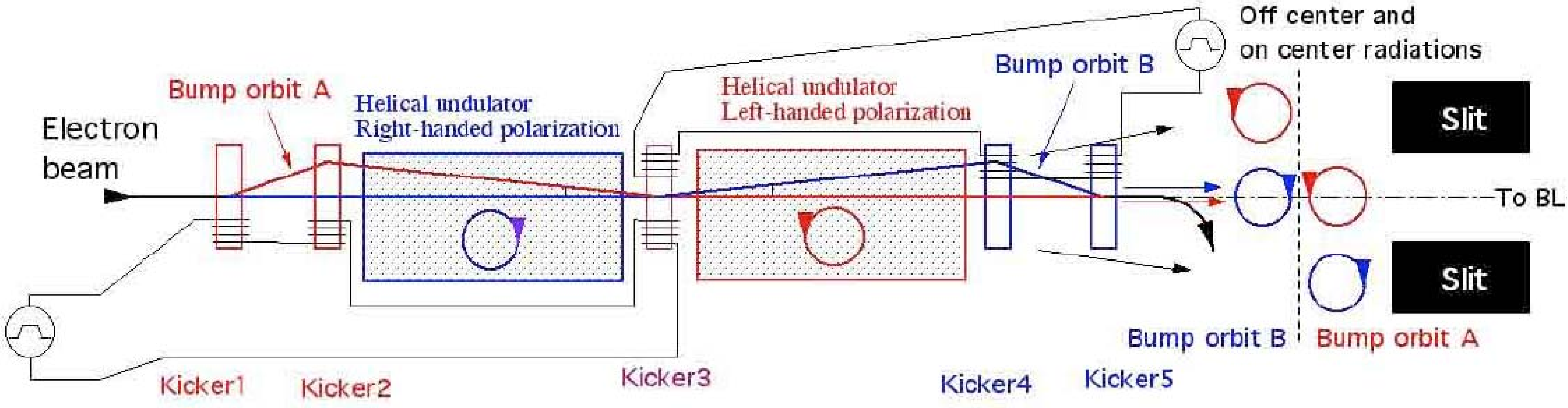
- In-vacuum diffraction chamber
- Polarization analysis

Under design; will be utilized at NSLS X1A prior to NSLS-II



Alternate canting scheme: dynamically-canted EPUs

T.Hara et al. http://www.sri2003.lbl.gov/pdf/Hara_Talk11.5_SRI03.pdf



Beam bump angular kicks: 0.16 mrad

Dynamic canting: issues

- Requirements imposed on accelerator systems
  - Dynamic canting requires 5 switching magnets → shorter EPUs
  - How would dynamic canting affect ring performance?
  - Dynamic canting makes achievement of orbit stability requirements more difficult

- Requirements imposed on beamline optics
  - Dynamic switching could simplify optics design (analysis underway)
  - Reduction in number of mirrors (6 → 2) → cost savings
  - How would dynamic canting affect beamline performance? (reproducibility of switching magnets determines polarization stability)

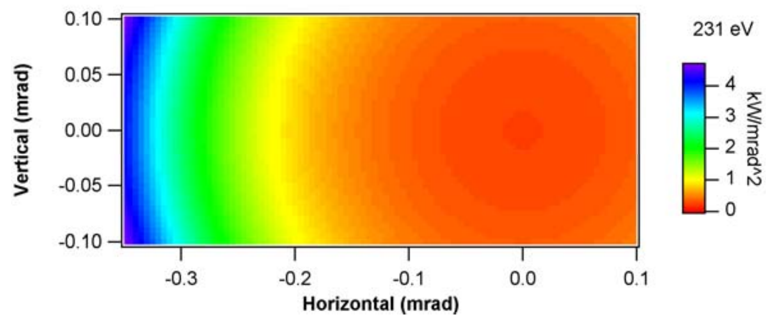
Requirements imposed on Conventional Facilities

In addition to the standard utilities (power, liquid nitrogen, compressed air, cooling water):

- Helium gas recovery
- Gas exhaust for experiments and roughing vacuum pumps
- Laboratory space in LOB or elsewhere for
  - sample mounting and assembly/repair of UHV endstation components
  - sample pre-alignment (optical microscope, rotating anode, MOKE, …)

Outstanding Issues

- Key design decisions still to be made
  - Dynamic vs. static fast switching polarization (task force group involving the accelerator group)
  - Need for M_0 (thermal considerations, FEA). Note: currently M_0 is not included



  - Location of branching mirror – affects spot sizes in the branch line and the space available for the first endstation
- Risks
  - Dynamic switching poses accelerator performance risk
  - Beamline performance depends on achieving mirror and grating quality (figure and finish) beyond FY2007 state-of-the-art (will require R&D)

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Cost Estimate

1.04.05.04 Undulator Beamline 4 - Soft X-ray Coherent Scattering

Component	
Enclosures	$ 174,598.00
Beam Transport	$ 206,807.00
Utilities	$ 227,774.00
High Heatload Optics	
Beam Conditioning Optics	
Personnel Safety System	$ 96,894.00
Equipment Protection System	$ 140,144.00
White Beam Apertures	$ 262,817.00
White Beam Components	
End Station 1	$ 1,869,898.00
End Station 2	
Beamline Controls	$ 120,756.00
Beamline Control Station	$ 35,686.00
Satellite Building	
Beamline Management	$ 1,261,295.00
Branching Mirror	$ 598,408.00
Exit Slits	$ 1,102,562.00
First Mirrors (m0 and M1)	$ 1,111,344.00
Monochromator (m2 + gratings)	$ 1,565,745.00
Polarization Selection Components	$ 243,890.00
Refocusing Mirror	$ 2,730,113.00
Specialized White Beam Comp	
Grand Total	**$ 11,748,731.00**

Summary

- High performance soft x-ray beamline design
  - High flux, at high resolution, from 200 to 2000 eV
  - Fast-switching polarization capability
  - Ability to serve wide variety of experiments

- Beamline advanced conceptual design work is in progress, with decisions to be made regarding:
  - Fast switching polarization mode
  - R & D to improve optics figure and finish