5-WAY MEETING

R&D REQUIREMENTS AS DRIVEN BY NEXT GENERATION BEAMLINES AT THE ADVANCED PHOTON SOURCE

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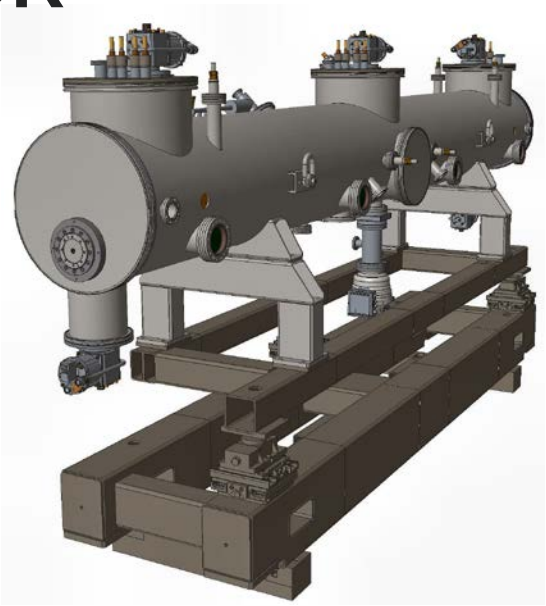
Detectors:	**Nino Miceli**
Optics:	**Lahsen Assoufid**
Nanopositioning Instrumentation:	**Deming Shu**
Beamline Instrumentation:	**Mike Fisher** **Gary Navrotski**
Scientific Software & Data Management:	**Nicholas Schwarz**

APS-U ACCELERATOR REQUIREMENTS

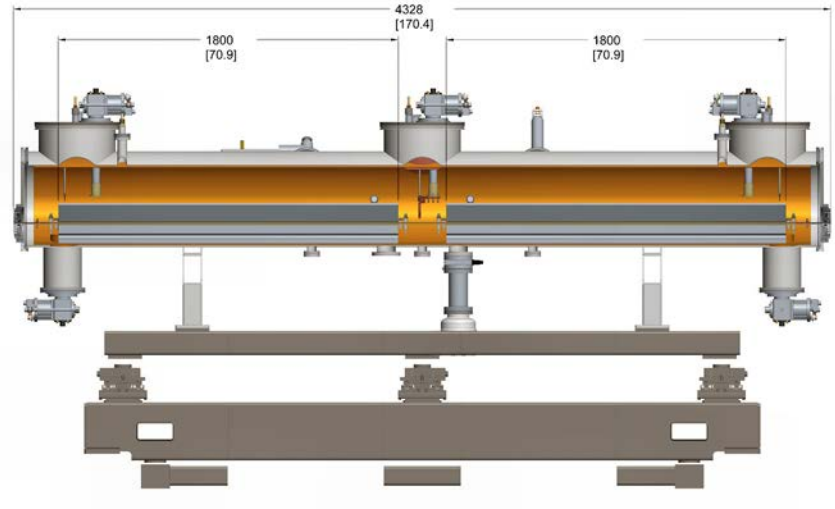
Vacuum	Gas scattering lifetime	30 hrs after 1000 A-hr
	Average residual gas pressure	2 nTorr
Magnets	Max quadrupole gradient	97 T/m
	Max field ratio in longitudinal gradient BM	5
	Magnet-to-magnet alignment tolerance	30 µm rms
Controls	Time-synchronous data acquisition	Across several subsystems
Mechanical Supports/ Diagnostics/Orbit-stability	Beam stability	400 nm AC rms, 0.01-1000 Hz
	Real-time orbit feedback	@ 22.4 kHz
	Closed-loop BW	1 kHz
	Absolute beam size monitor resolution	1.8 µm rms
Power Supplies	Current stability	10 ppm AC rms
	Reproducibility (1 week)	10 ppm rms
Pulsed Injection System	Rise & fall time	4.7 ns
	Pulser voltage	> 15 kV
	Pulser MTBF	> 1 year
Injector	Particle Accumulator Ring	20 nC stored, 1 Hz cycle
	Booster	18 nC

SUPERCONDUCTING UNDULATOR R&D REQUIREMENTS

- Phase error of less than 3°.
- Periods ranging from 1.6 cm to 2.0 cm.
- Modular cryostat, expandable to 4.5 m.
- Cryostat to accommodate multiple devices in same straight section, either in tandem or canted.



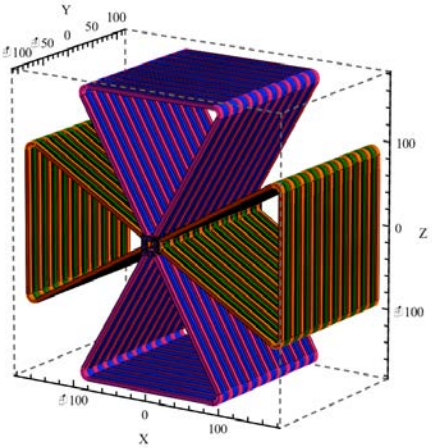
NbTi winding, 1.5-m-long device for LCLS prototype

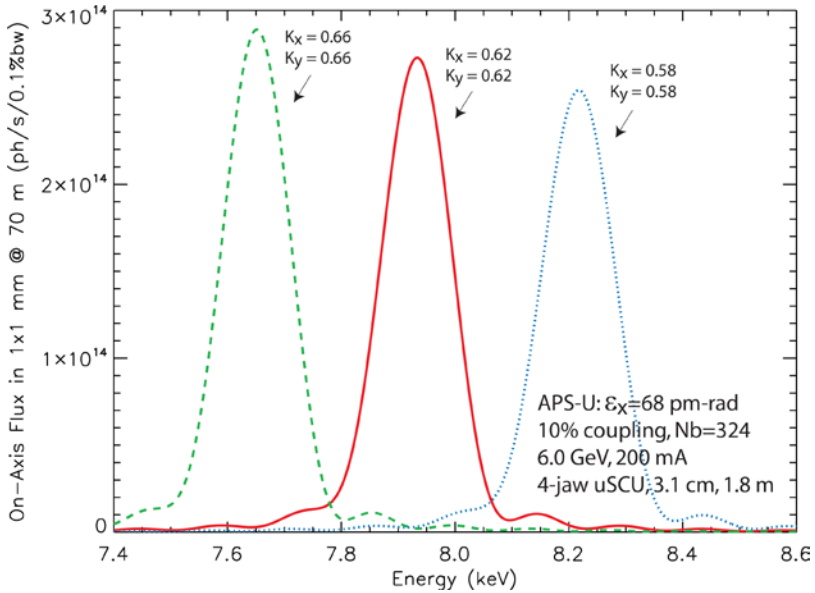


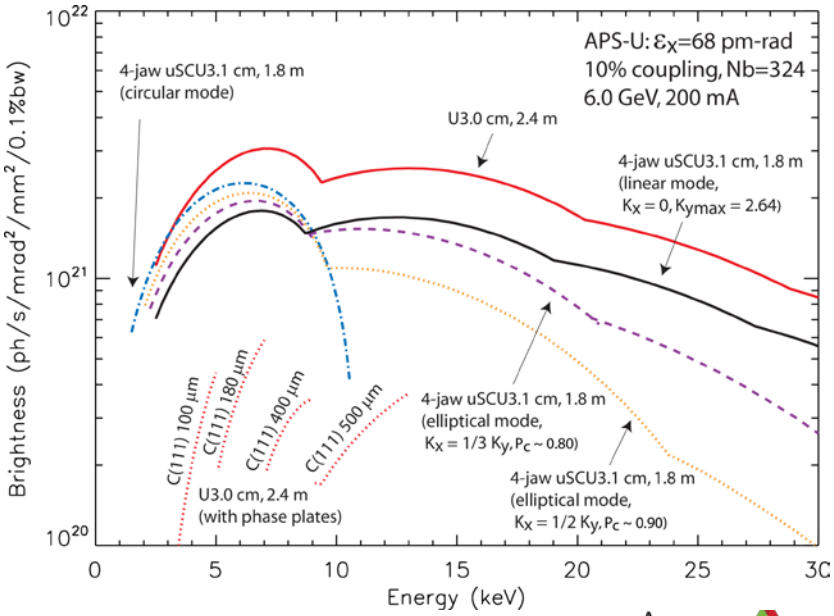
New 4.5 m Cryostat System

SUPERCONDUCTING ARBITRARY POLARIZING EMITTER (SCAPE)

- A 4-jaw superconducting undulator for providing variable polarization source.
- Provides both circular and linear polarization.
- Two 1.8m long devices in one cryostat.
- For polarization studies operate one device in RCP and other LCP and shift the current slightly in each for fast switching.







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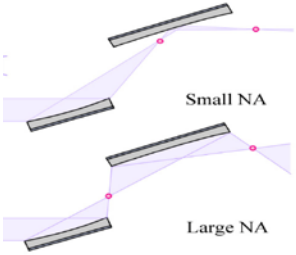
Detector Requirements for APS-U era

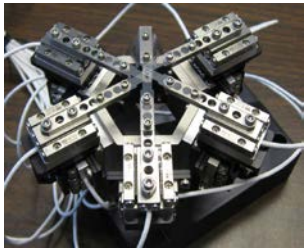
Requirement	Specs	Techniques	Detector Options
High dynamic range integrating area detectors at high energy	Dynamic range > 10^7 , <100 keV, 50-100 μm pixels, kHz frame rates	Bragg CDI, ptychography, surface diffraction, combined Bragg-diffuse ("total scattering")	MM-PAD (Cornell)
High spatial resolution at high energies	≦5 μm resolution, <100 keV, dynamic range > 10^7, Hz frame rates	High energy Bragg CDI, Imaging	Scintillators, Mönch-like (PSI), CMOS Imaging Sensors
MHz-framing integrating area detectors	>6.5 MHz burst rate, 10^4-10^5 dynamic range, 50-100 μm pixels	Ultra-fast diffraction (non-reversible phenomena)	Keck PAD (Cornell), EU-XFEL detectors (AGIPD, LPD, DSSC), FASPAX (ANL/FNAL)
μs photon timing tagging	Dynamic range 1-4 bits, Pixel size 50 μm	XPCS	VIPIC (FNAL, BNL, ANL), Timepix-3 (Europe)
High spatial resolution at high speeds	≦1 μm resolution, >6.5 MHz burst rate	Ultra-fast imaging	Scintillators and CMOS Imaging Sensor
Polarization detection	Direct and efficient polarization detection	Magnetic diffraction/spectroscopy	Gas-Filled Microchannel Plates
Fluorescence detection	ΔE ~ 100 eV; throughput approaching bunch frequency (10-100 MHz); many channels	XRF, XAS, scanning nanoprobes	Silicon Drift Diodes Arrays, MAIA v2.0 (BNL)
Emission detection	ΔE ~ 1 eV, 1 MHz count rates	XRF, XAS, XES, scanning nanoprobes	Transition Edge Sensors (NIST/ANL/SLAC)

APS OPTICS R&D REQUIREMENTS

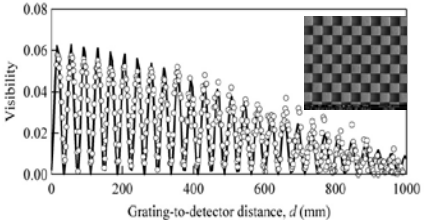
- **Highly stable (<50 nrad), efficient cryo-cooling technology for wavefront-preserving crystal monochromators and mirrors/multilayer optics**
  - Expected heat load: ~ 250 W/mm^2 at 30 m for monochromators; ~ 1 kW for mirrors.
- **Coherence-preserving deformable mirrors and adaptive optics**
  - Deformable mirrors for dynamic focusing, collimation and zoom optics with focal spot sizes ranging from 50 nm to a few microns. This will benefit many nano- and microprobe beamlines.
- **Extreme precision mirrors and multilayers optics**
  - Collimation (RIXS), high energy x-ray focusing (11-ID and many others).
  - multilayer Laue lens optics to focus high energy x-rays to < 10 nm (Collaboration with BNL).
- **High aspect ratio zone plates**
  - Current goal: focus to 20 nm for high energy x-rays.
  - Ultimate goal: zone plates using novel fabrication techniques to focus to <20 nm.
- **Crystal optics for high resolution and wavefront preservation**
  - Advanced fabrication, processing and orienting tools for Si and exotic materials.
- **Coherence-preserving compound refractive lenses with < 200 nm focal spot size**
- **Coherence-preserving beamline vacuum window systems**
- **Optical metrology for ultraprecise mirrors**
  - 2-D surface metrology tool for steeply curved aspheric mirrors with <1 nm figure error and < 50 nrad rms slope error, to support both in-house fabrication efforts as well as quality control of extreme precision mirrors for the APS future nanoprobes.
- **At-wavelength metrology and wavefront sensors**
  - Non-invasive wavefront sensors for beamline wavefront diagnostics and adaptive optics control.



Modified from Takashi Kimura et al. Opt. Express 21.8 (2013)



Multiple Fresnel Zone Plates Precision Alignment Apparatus
S. Gleber, et al., Optics Express, Vol. 22, No. 23, DOI: 10.1364/OE.22.028142, 2014.
D. Shu, et al., Proceedings of MEDSI-2014, Melbourne, Australia, Oct. 2014.



Visibility evolution along 34-ID E beamline optical axis at 8 keV measured using a 2D checkerboard phase grating
[Rev. Sci. Instrum. 87 (2016)]

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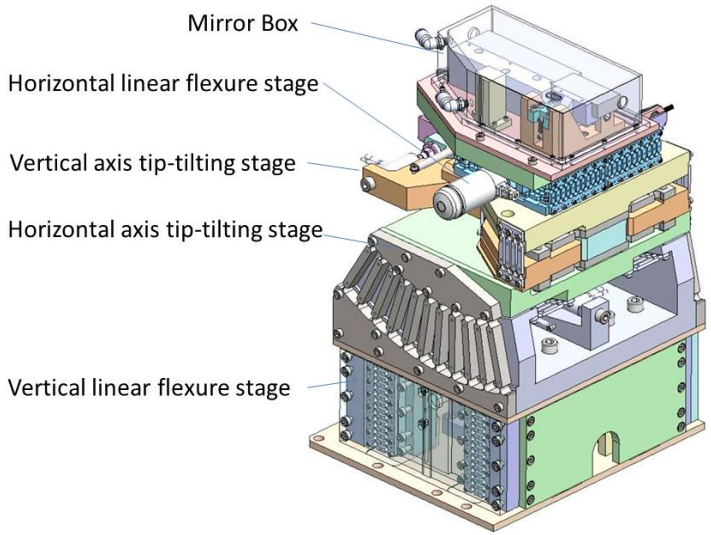
NANOPOSITIONING REQUIREMENTS

- Design of stages for x-ray nanofocusing K-B mirror optics with <20 nm focal spot and >30 mm working distance.
  - Angular position resolution and stability requirements ~ 5 - 10 nrad.
- Nano-positioning sample stages for hard x-ray in-situ nanoprobes.
  - Stringent stability requirements (e.g. vibrations) and rapid scanning capability.
  - Variable sample environments.



Mirror box stage at APS beamline 34-ID-E

D. Shu, W. Liu, J. Maser, B. Lai, S. Kearney, J. Anton, Z. Cai, R. Harder, R. Xu, L. Assoufid, S. Vogt, and J. Z. Tischler, "Design of multidimensional flexure stage system for hard x-ray mirror focusing at sub-50-nanometer scale," Proceedings of ASPE 2013 Annual Meeting, St. Paul, MN, Oct. 2013.

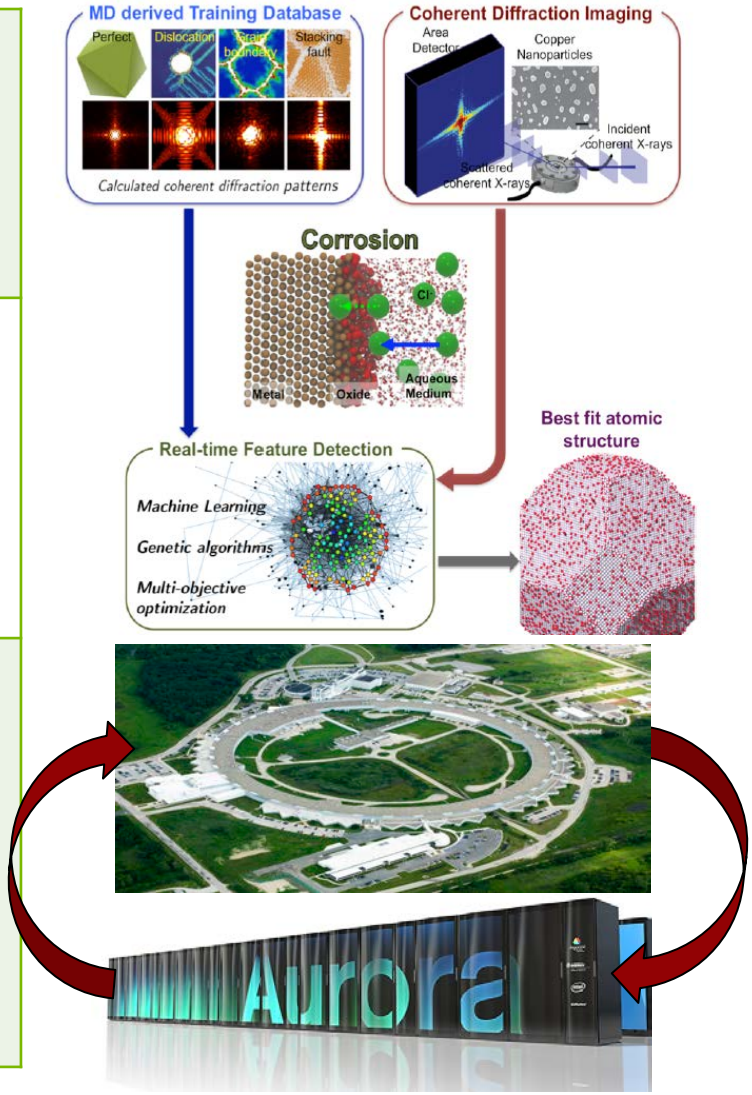
Velociprobe - high-speed, high-resolution X-ray nanoprobe
C. Preissner, D. Vine (ALS), and collaborators

SOFTWARE & COMPUTING R&D REQUIREMENTS

- Mathematical optimization methods.
- Theory and algorithms for multimodal data integration (e.g. combining structural and dynamics studies).
- Machine learning to determine proper reconstruction parameter space based on sample characteristics.

- Algorithms and tools to compare results with models/simulations and previously collected experimental data.
- Statistical methods and tools, segmentation algorithms to automatically determine ROIs and track features in real-time to steer acquisition.

- Workflow and pipeline automation.
- Resource scheduling and preemption for on-demand use of leadership class computing resources; application of virtualized and containerized computing environments.
- Data management tools and portals (APS currently collects approximately 2PB/year; at least 2 order of magnitude increase over next decade).



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