National Synchrotron Light Source II

NAPAC 2022

Recent Developments of the Soft X-ray Beam Position Monitor Project

Boris Podobedov*

August 11, 2022

North American Particle Accelerator Conference

* boris@bnl.gov, primary affiliation Electron−Ion Collider, BNL

U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY

sXBPM Project Team

Stony Brook University

Dmitri Donetski

Kevin Kucharczyk

Jinghe Liu

Ricardo Lutchman

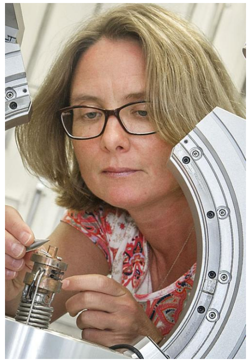
Brookhaven National Laboratory

Daniel Bacescu

Christopher Eng

Steven Hulbert

Claudio Mazzoli



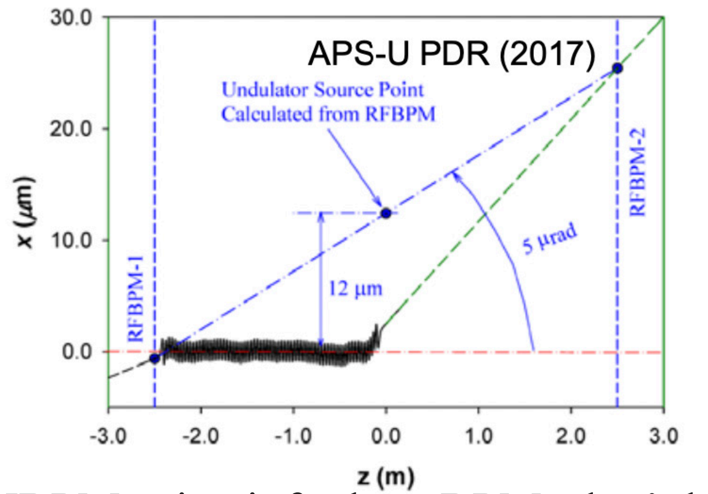
Christie Nelson

BP

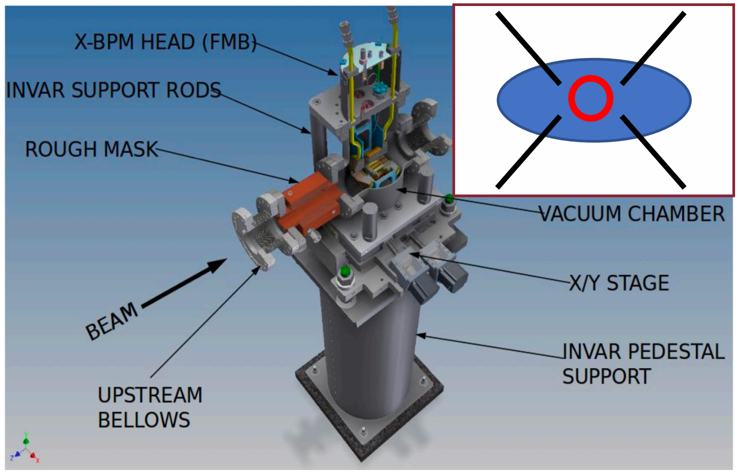
Boris P.

Motivation for Novel X-Ray BPMs

- Modern synchrotron light sources are all about photon beam brightness and stability
- X-ray beam must be stable at the user sample (position, wavefront, intensity)
- Need stability of e-beam, and of all beamline elements, starting from the undulator source
- Real-time diagnostics & feedbacks must rely on XBPMs, both white beam and mono
- White-beam XBPMs are especially important, being upstream of any beamline optics
- Standard solution (blade photoemission XBPMs) does not work for coherent soft X-ray beamlines
- Non-invasive XBPMs which preserve the coherence of the beam are still needed



XBPMs give info that eBPMs don't have



"standard solution": doesn't work for coherent soft X-ray beamlines

Soft X-ray BPM (sXBPM) R&D Project at NSLS-II

Approach

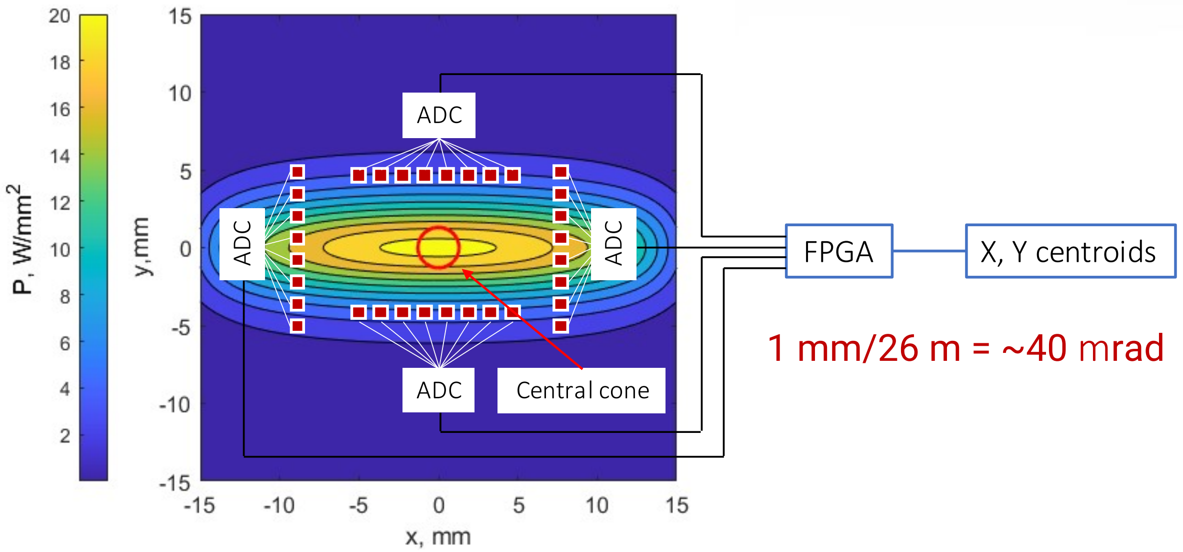
- Place custom-made GaAs photodiode arrays into outer portions of X-ray beam and calculate beam position from pixel photocurrents

Potential advantages

- High sensitivity: E=1 keV photon yields E/(4eV)~250 photoelectrons in GaAs, vs. ~1 in metal blades
- Multi-pixel arrays: better positional resolution, spatial feature resolution, ability to discriminate stray light from bend magnets and other sources

Goals and constraints

- Prototype to be installed and tested in C23-ID NSLS-II canted soft X-ray undulator beamline FOE (white beam, 26 m from EPU source)
- ~1 micron positional resolution @ 10 Hz sampling, all undulator K parameter values, linear polarization
- Coherence preservation, no interference with beamline operations



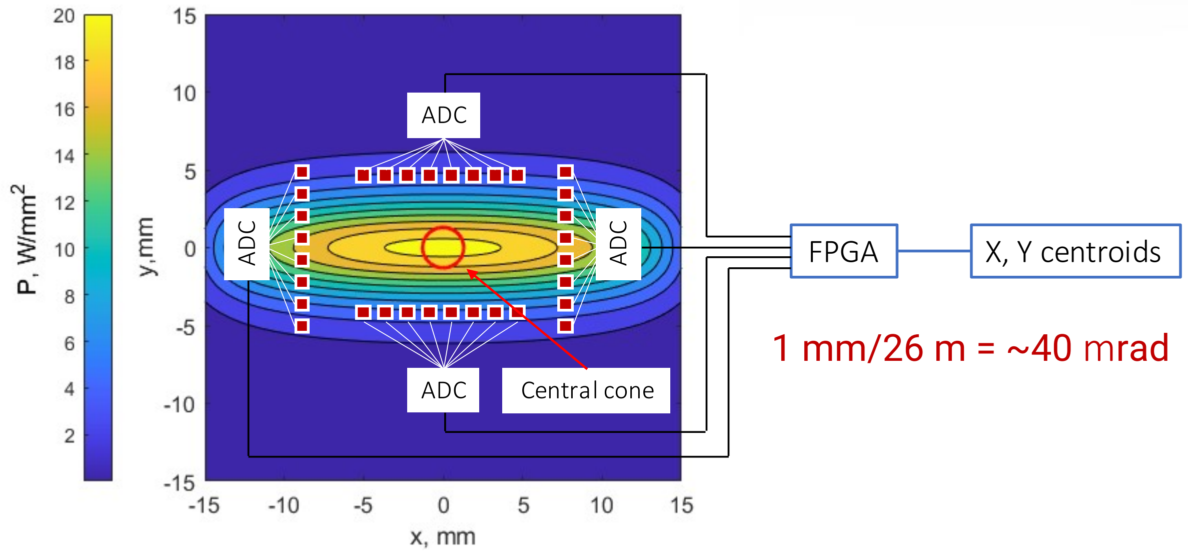
SXBPM concept

J. Liu et al., MOPAB121, proc. IPAC'21

Soft X-ray BPM (sXBPM) R&D Project at NSLS-II

Challenges

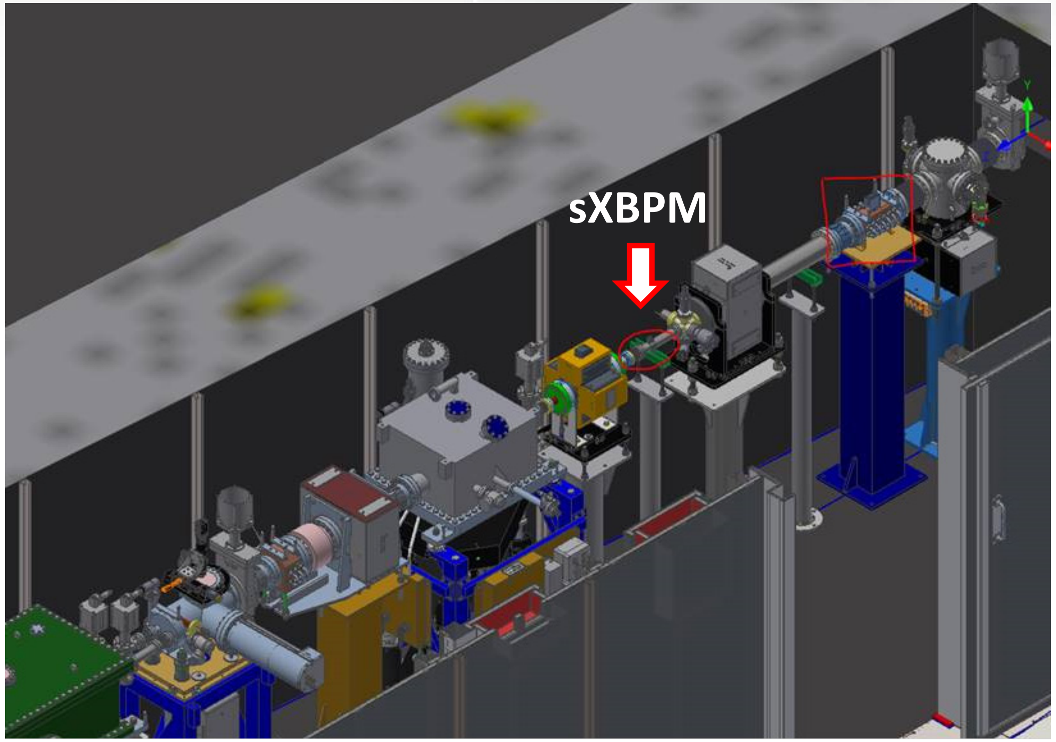
- High power density (at high K) => potentially high heat load and detector photocurrents
- Detectors must operate in UHV
- Compatibility with existing beamline operations
- sXBPM mechanical stability
- Systematic errors due to widely varying beam profile with changes of ID gap and phase
- Contamination of ID radiation with that from the closest dipole and other magnets

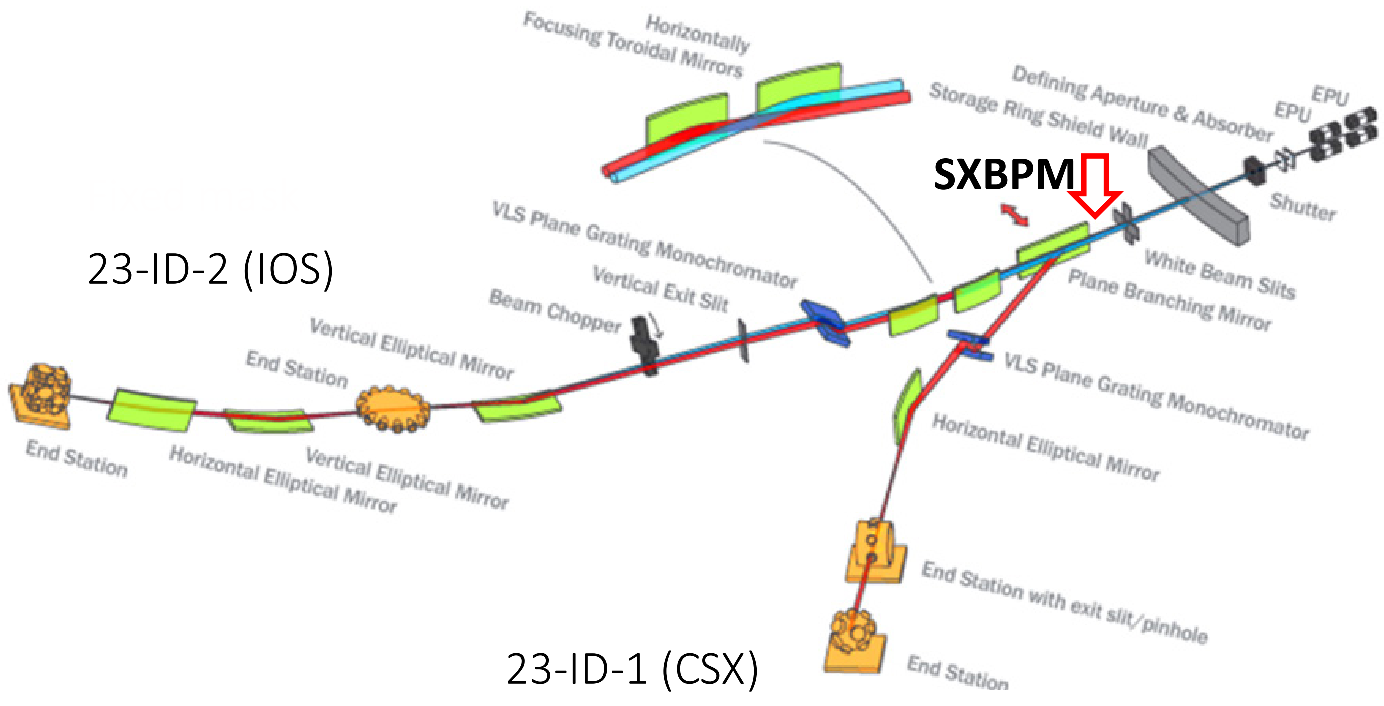


SXBPM concept

J. Liu et al., MOPAB121, proc. IPAC'21

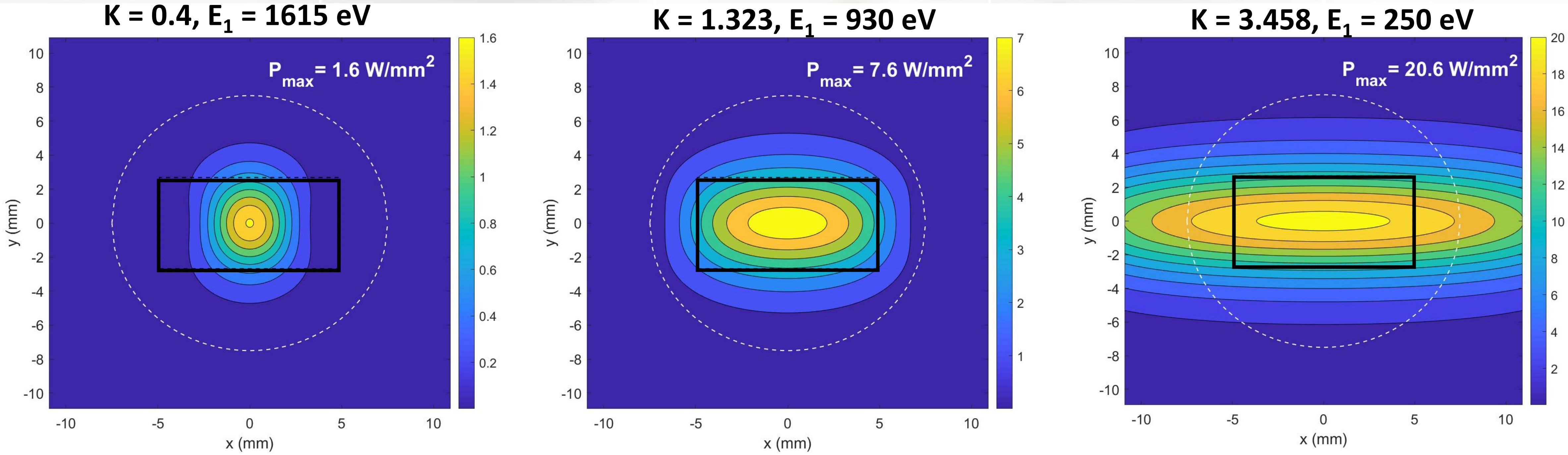
sXBPM Location at 23-ID FOE





- White high-power beam, outside of the ring tunnel at First Optics Enclosure (FOE)
- Two operating soft X-ray beamlines, 0.25 keV to 2 keV: IOS and CSX
- sXBPM ~1 m downstream of the FOE mask (~10x5 mm^2 water-cooled aperture)

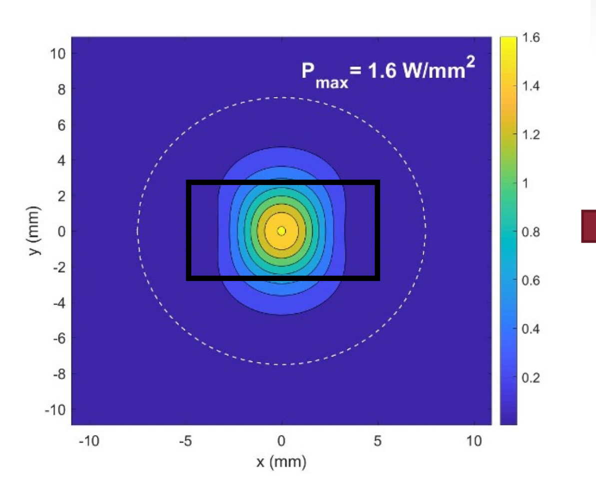
Beam Power Density at sXBPM Location

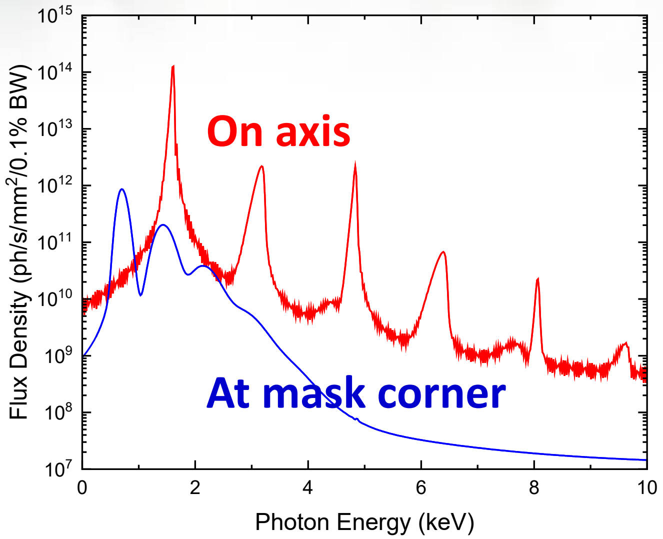


- Power density of undulator radiation 26 m downstream of the CSX undulator (λu = 49 mm, L = 2 m) at different magnetic strength settings in linear horizontal polarization
- Photons outside the rectangle (=fixed mask projection) do not reach the sXBPM
- Photodiodes should be able to operate at power densities up to 20 W/mm^2

Desired Detector Spectral Responsivity

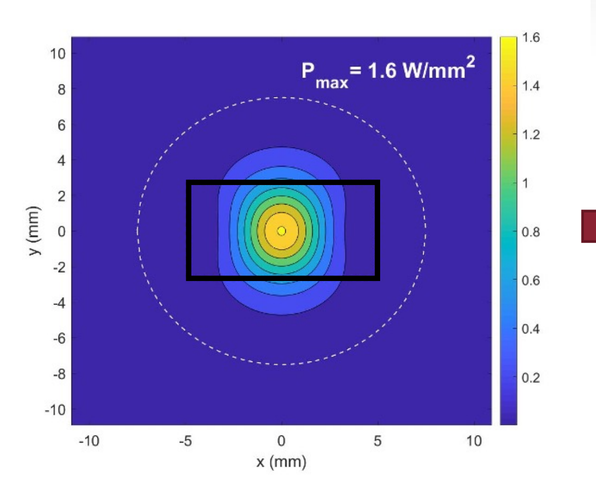
K = 0.4, E_1 = 1615 eV

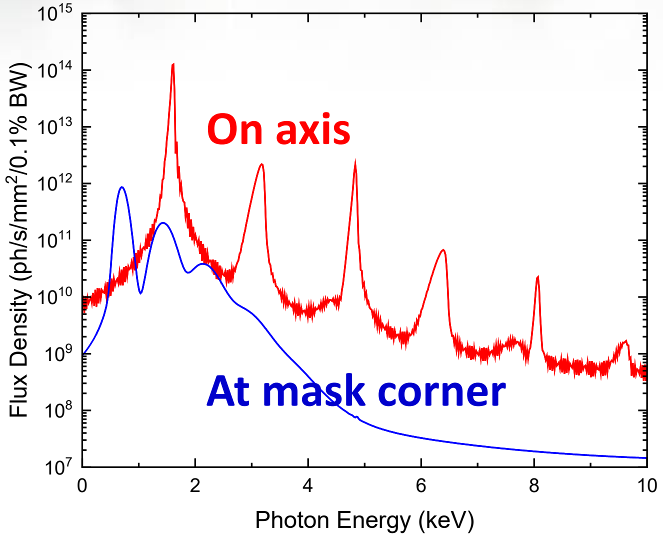




Desired Detector Spectral Responsivity

K = 0.4, E_1 = 1615 eV

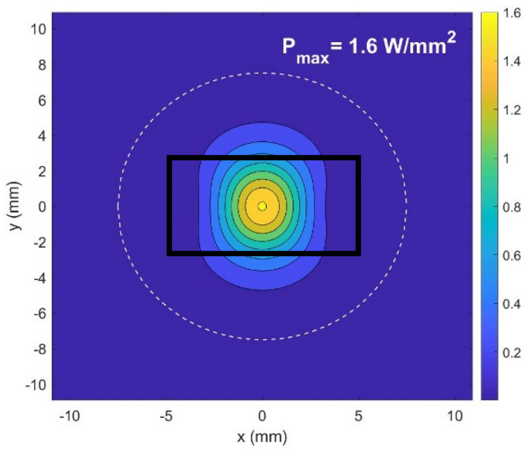


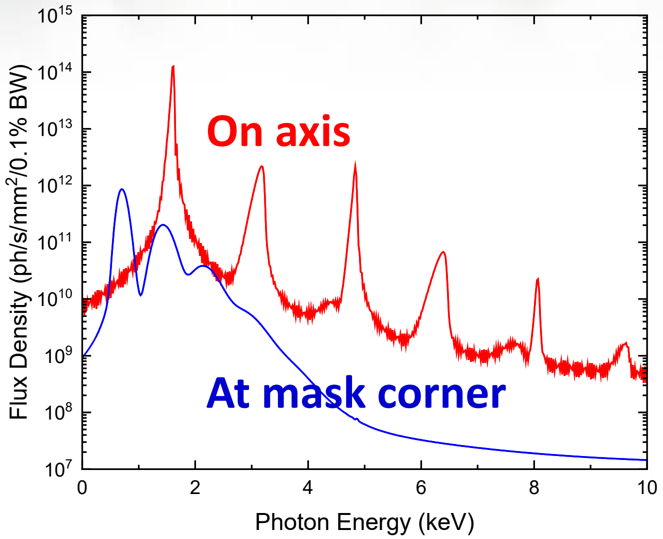


- Must have spectral coverage (high responsivity) from ~650 eV to at least 2 keV, as defined by low-K operation

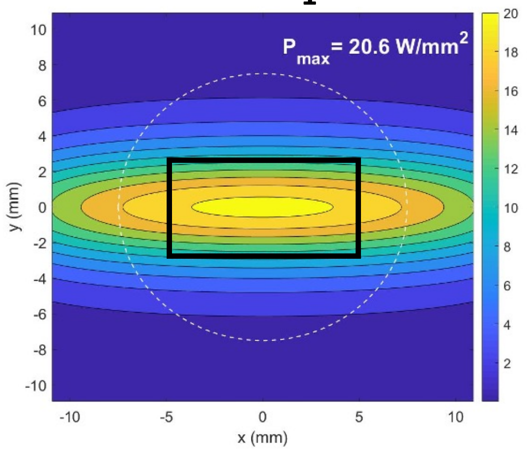
Desired Detector Spectral Responsivity

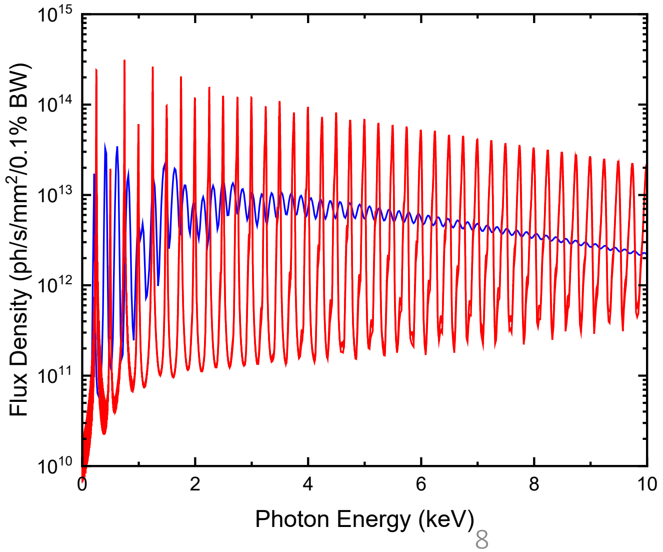
K = 0.4, E_1 = 1615 eV





K = 3.458, E_1 = 250 eV

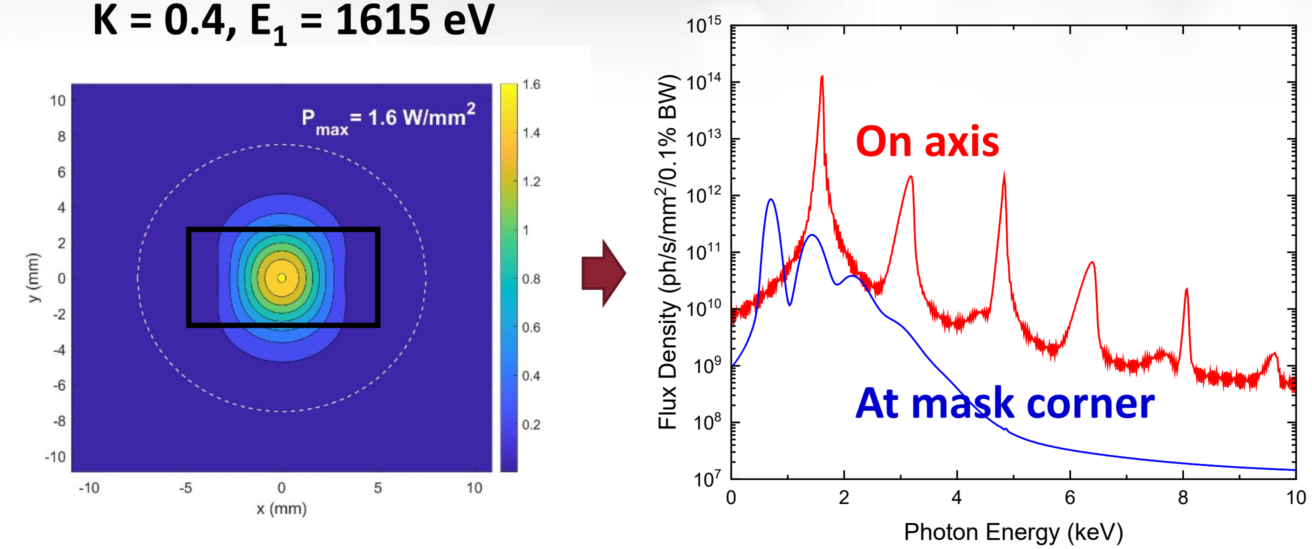




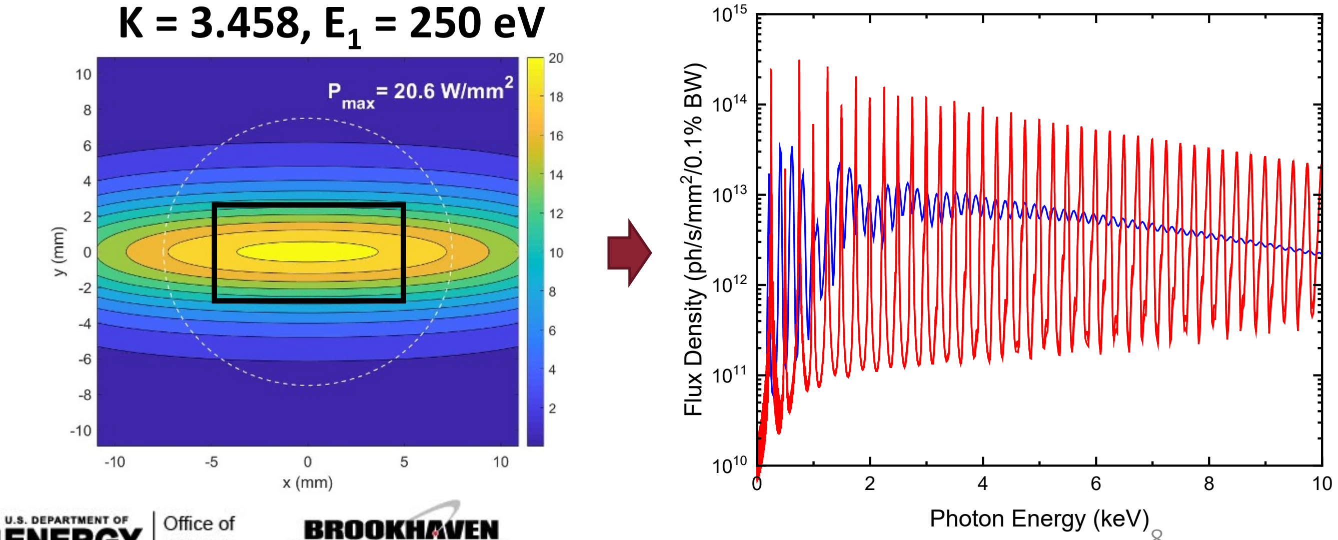
- Must have spectral coverage (high responsivity) from ~650 eV to at least 2 keV, as defined by low-K operation

Desired Detector Spectral Responsivity

K = 0.4, E_1 = 1615 eV



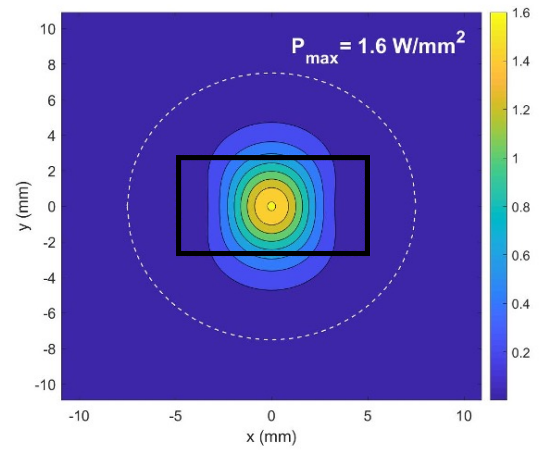
K = 3.458, E_1 = 250 eV

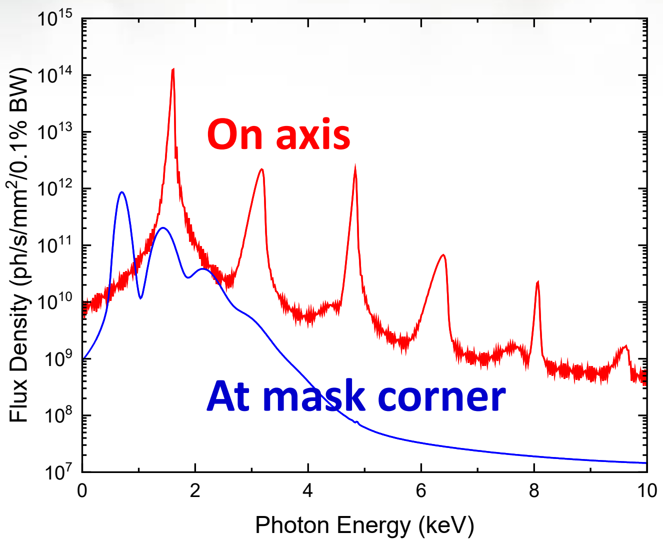


- Must have spectral coverage (high responsivity) from ~650 eV to at least 2 keV, as defined by low-K operation
- At high K, high power is mainly coming from hard X-ray (i.e. on-axis, 80% @ 2-16 keV)

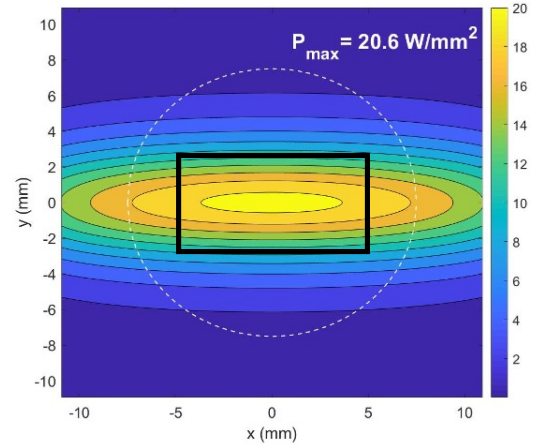
Desired Detector Spectral Responsivity

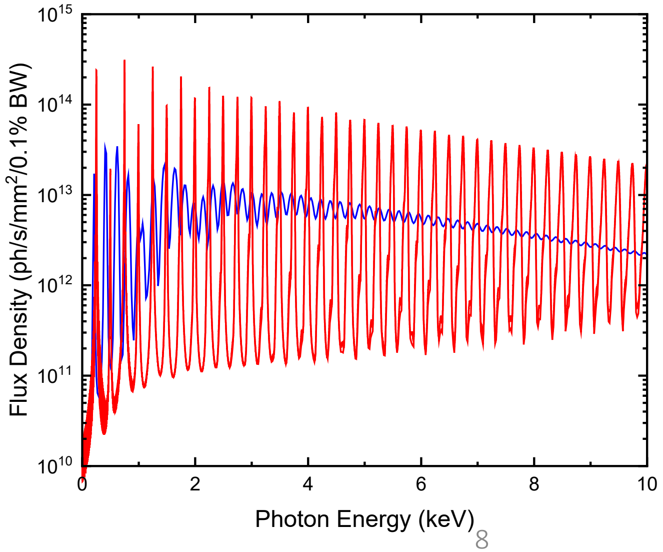
K = 0.4, E_1 = 1615 eV





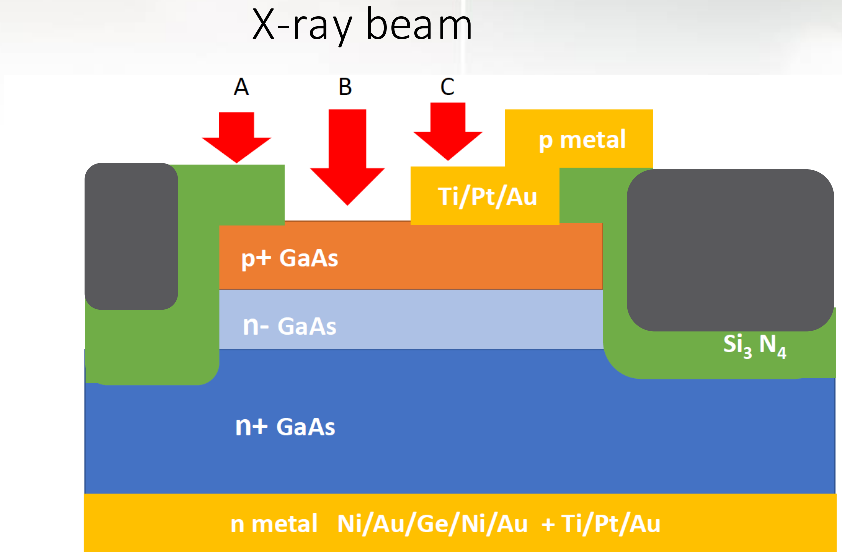
K = 3.458, E_1 = 250 eV



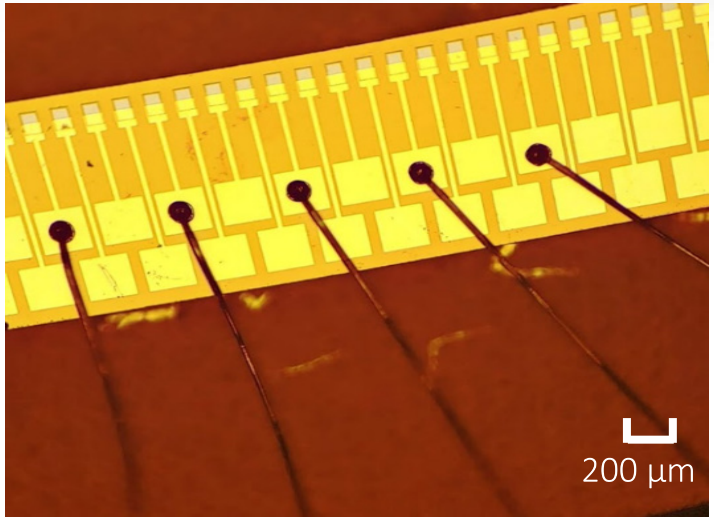


- Must have spectral coverage (high responsivity) from ~650 eV to at least 2 keV, as defined by low-K operation
- At high K, high power is mainly coming from hard X-ray (i.e. on-axis, 80% @ 2-16 keV)
- => Need low hard X-ray responsivity to keep manageable photocurrent density

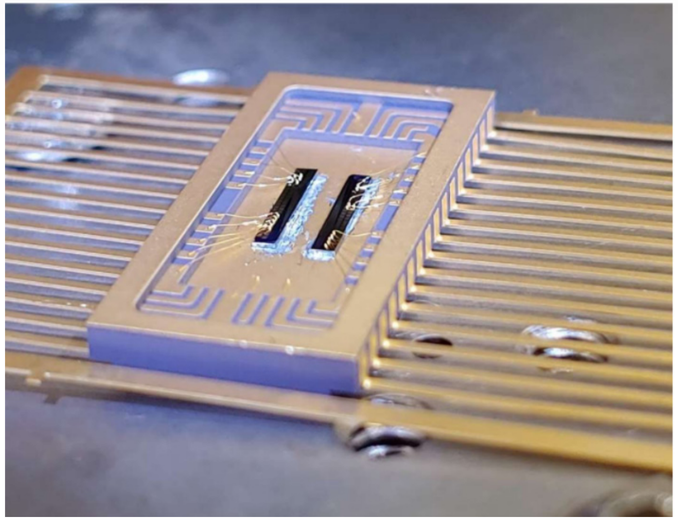
Detector Design, Fabrication, and Testing



The schematic cross-section of the prototype (not in scale) for measurements of the responsivity spectra at the end station: A, B, C three configurations studied



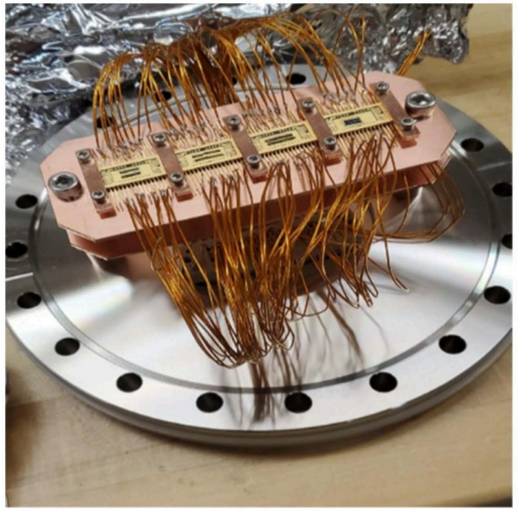
Photodiode array with 64 pixels



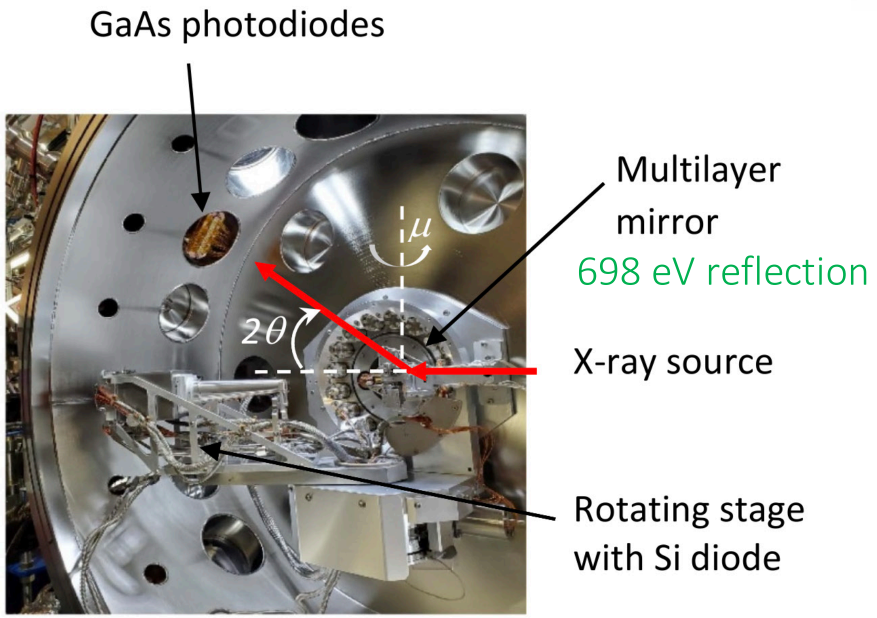
Leaded ceramic carrier with two photodiode arrays

- GaAs selected due to mature technology, ability to operate at high current density, and wide energy gap for temperature stability
- Devices with shallow p-n junctions for enhanced sensitivity in soft X-ray region were designed
- Wafers were grown by solid-source Molecular Beam Epitaxy for high quality of the top p-doped layer
- Photodiode arrays with 32 and 64 pixels were fabricated with pixels sizes from 2 x 6 to 60 x 50 µm^2
- Responsivity was measured with Ar-ion laser at 514 nm with power density up to 200 W/cm^2

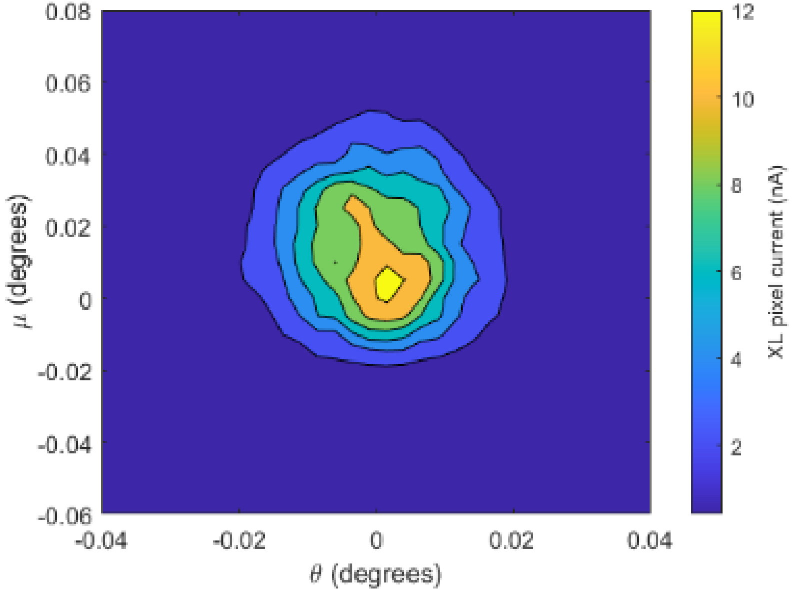
Responsivity Measurements in Soft X-ray at 23-ID-1 (CSX) beamline



Diode arrays in leaded ceramic carriers on customized 8’’ flange



CSX TARDIS chamber with diode arrays



Photocurrent map when scanning X-ray beam across detector pixel

Responsivity Measurements in Hard X-ray at 4-ID (ISR)

6-Circle Diffractometer

1710 XL Mounted in Diffractometer

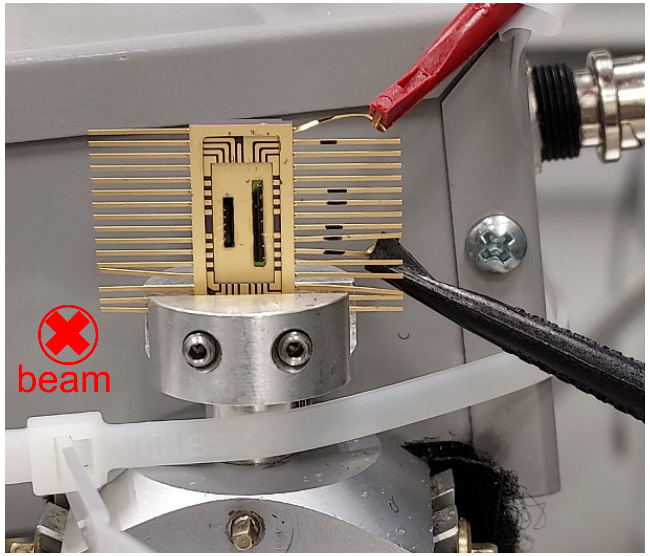
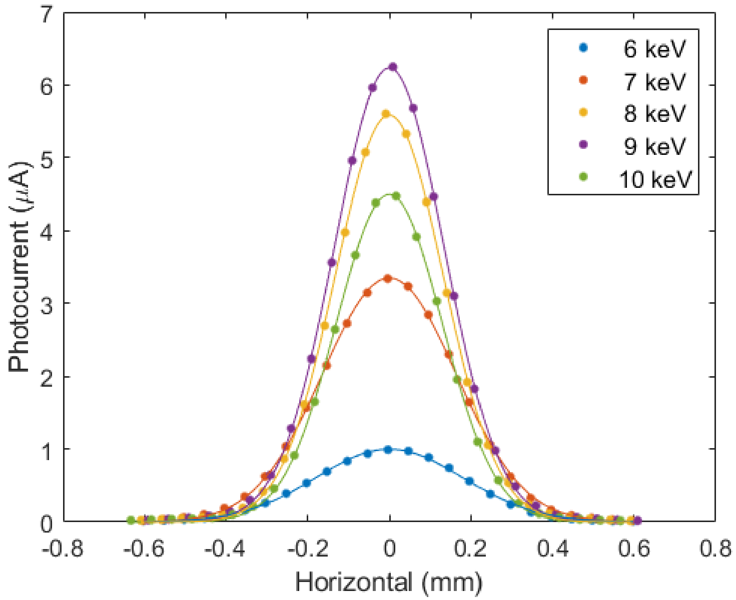
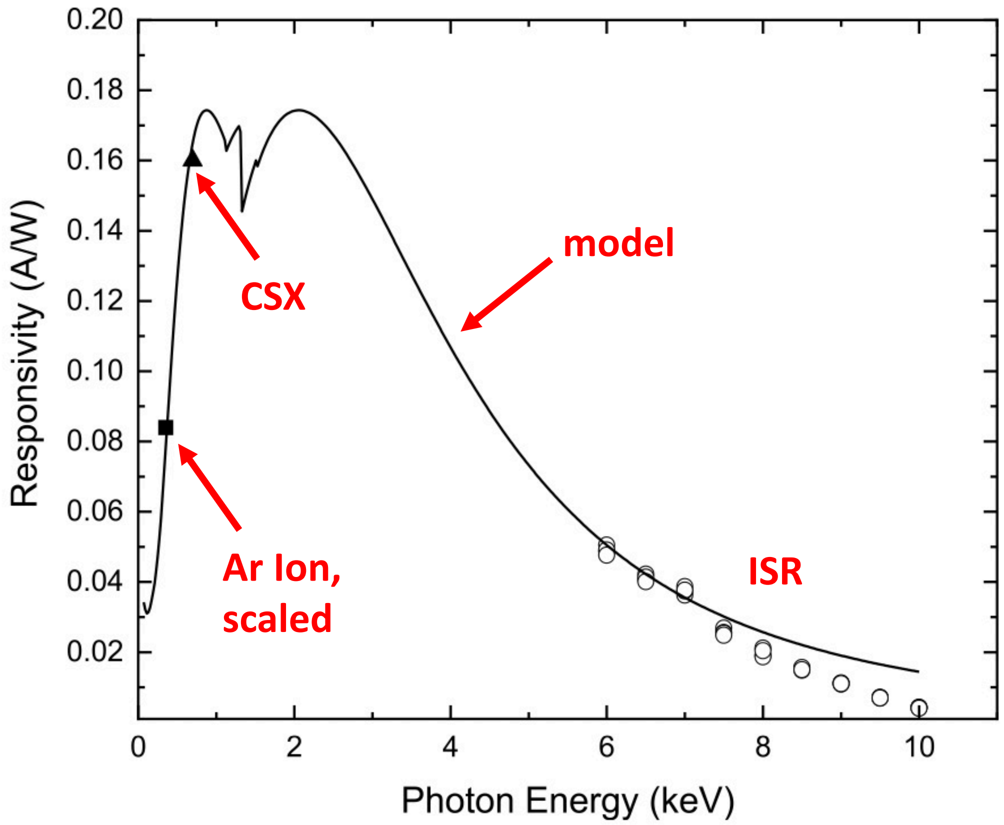


Photo-current vs. x-position scans



Measurement Parameters	
energy range	6-10 keV
incident beam intensity	$6 \times 10^{10} - 1 \times 10^{12}$ photons/s
horizontal beam size	320 – 490 mm (FWHM)
vertical beam size	45 – 60 mm (FWHM)

Measured Detector Spectral Responsivity



- Good responsivity in soft X-ray, rapid fall-off in hard X-ray, as needed for sXBPM
- Pixel-to-pixel uniformity
- Good device model

IOP Publishing

Semiconductor Science and Technology

Semicond. Sci. Technol. **37** (2022) 085024 (12pp)

https://doi.org/10.1088/1361-6641/ac7c88

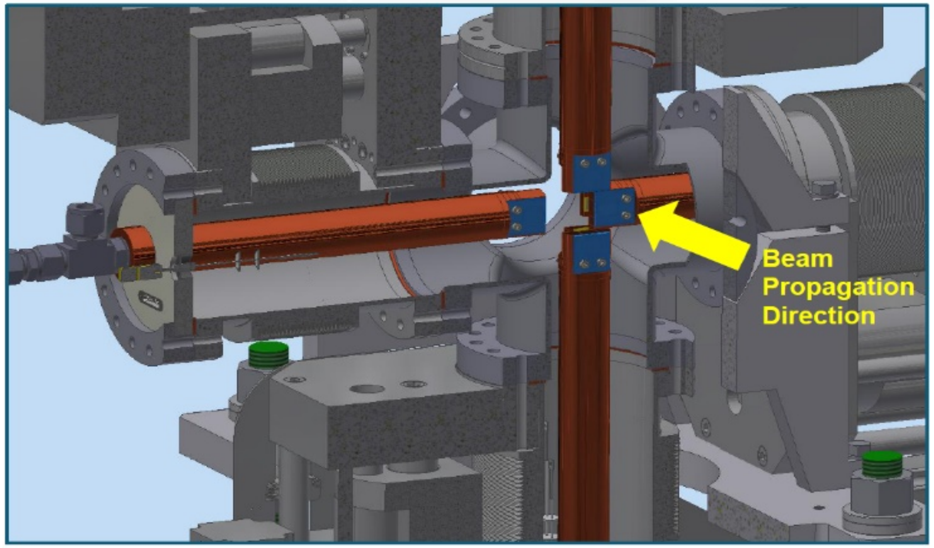
High power density soft x-ray GaAs photodiodes with tailored spectral response

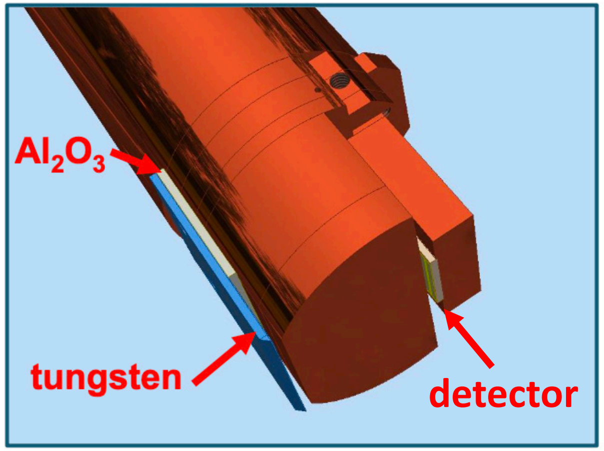
Dmitri Donetski[1], Kevin Kucharczyk[1], Jinghe Liu[1], Ricardo Lutchman[1], Steven Hulbert[2], Claudio Mazzoli[2], Christie Nelson[2] and Boris Podobedov[2,*]

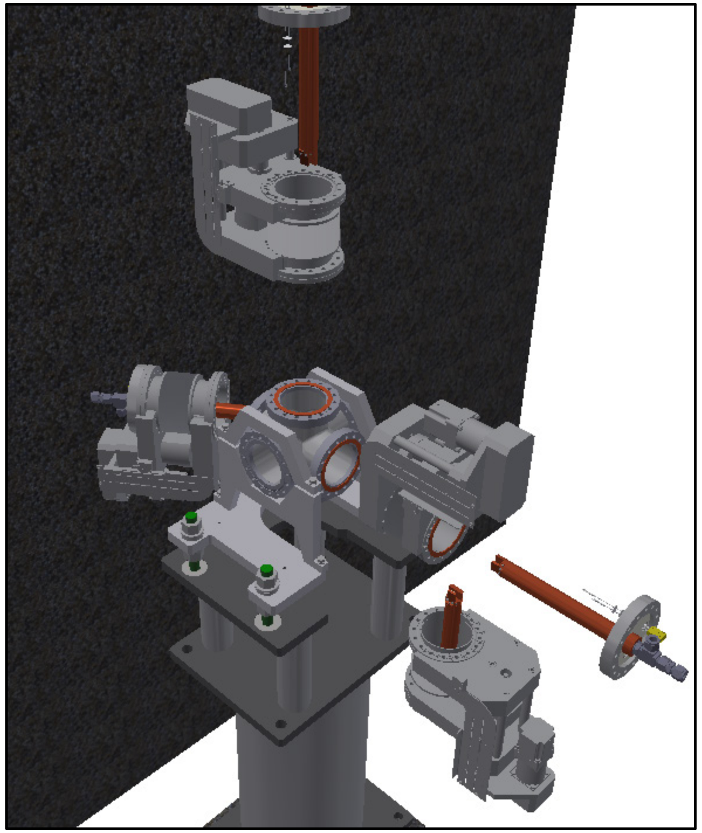
[1] Department of ECE, Stony Brook University, Stony Brook, NY 11794, United States of America

[2] Brookhaven National Laboratory, Upton, NY 11973, United States of America

Mechanical Design



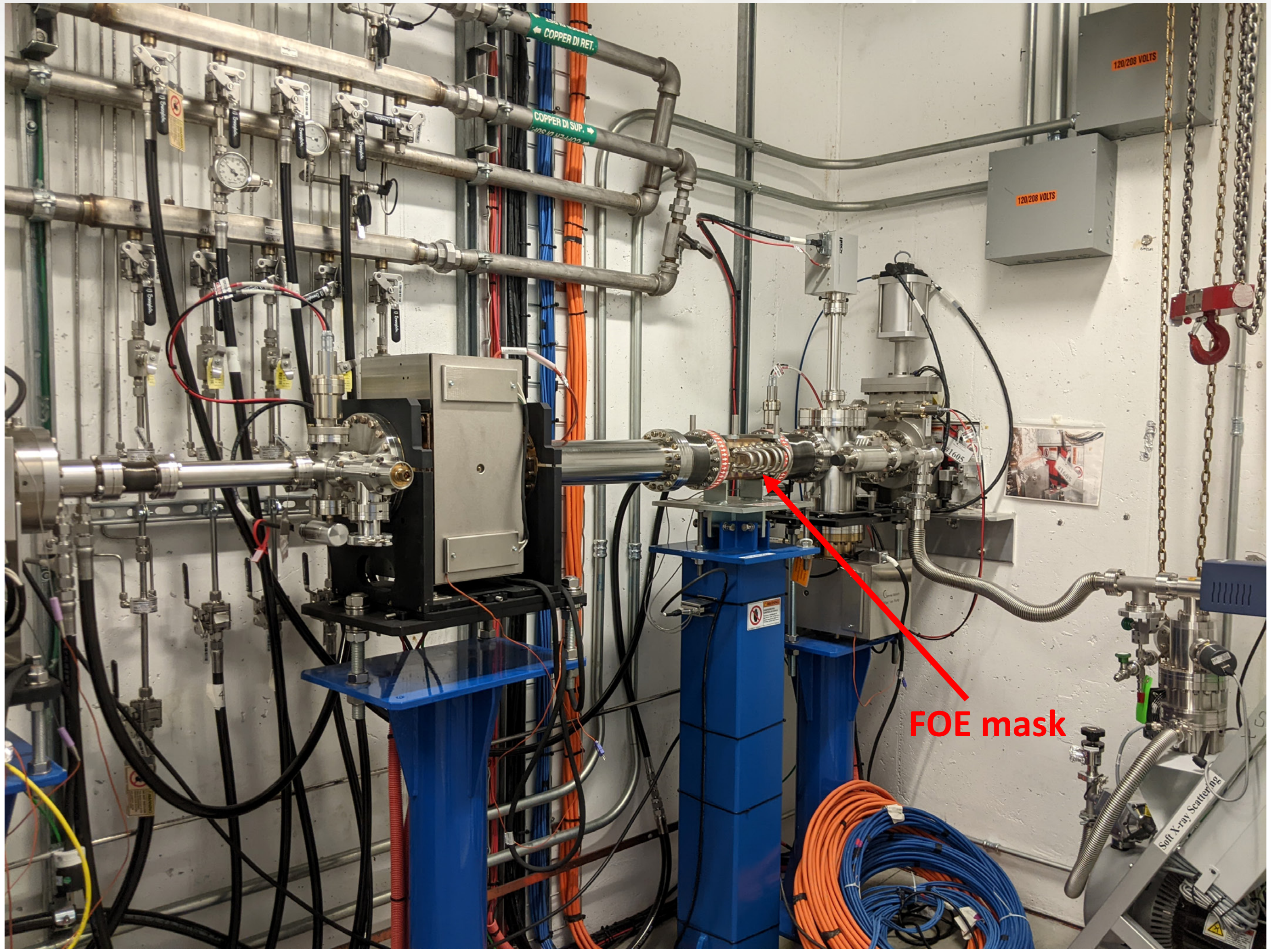




- Features: 4 water-cooled blade assemblies, single-axis translatable blades, tungsten shields with array of holes to reduce heat flux to the detector
- Challenges: stability, heat load management, compactness to fit the FOE, accessibility for modifications, alignment
- Status: design complete, components procured or fabricated, vacuum envelope installed

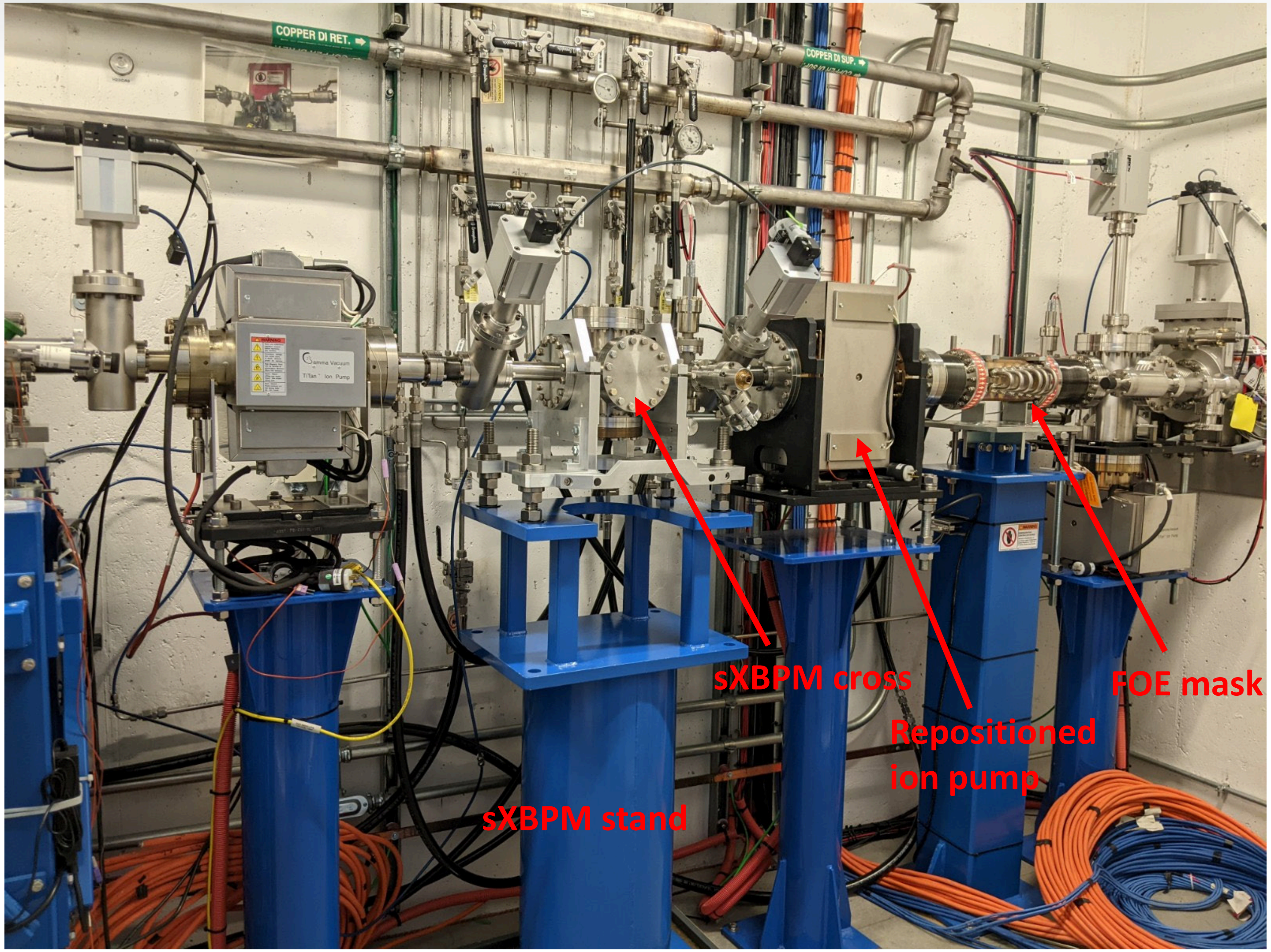
C. Eng et al., MOPC01, proc. MEDSI'2020

Vacuum Envelope Installation: pre-install



23-ID FOE
Apr. 21, 2022

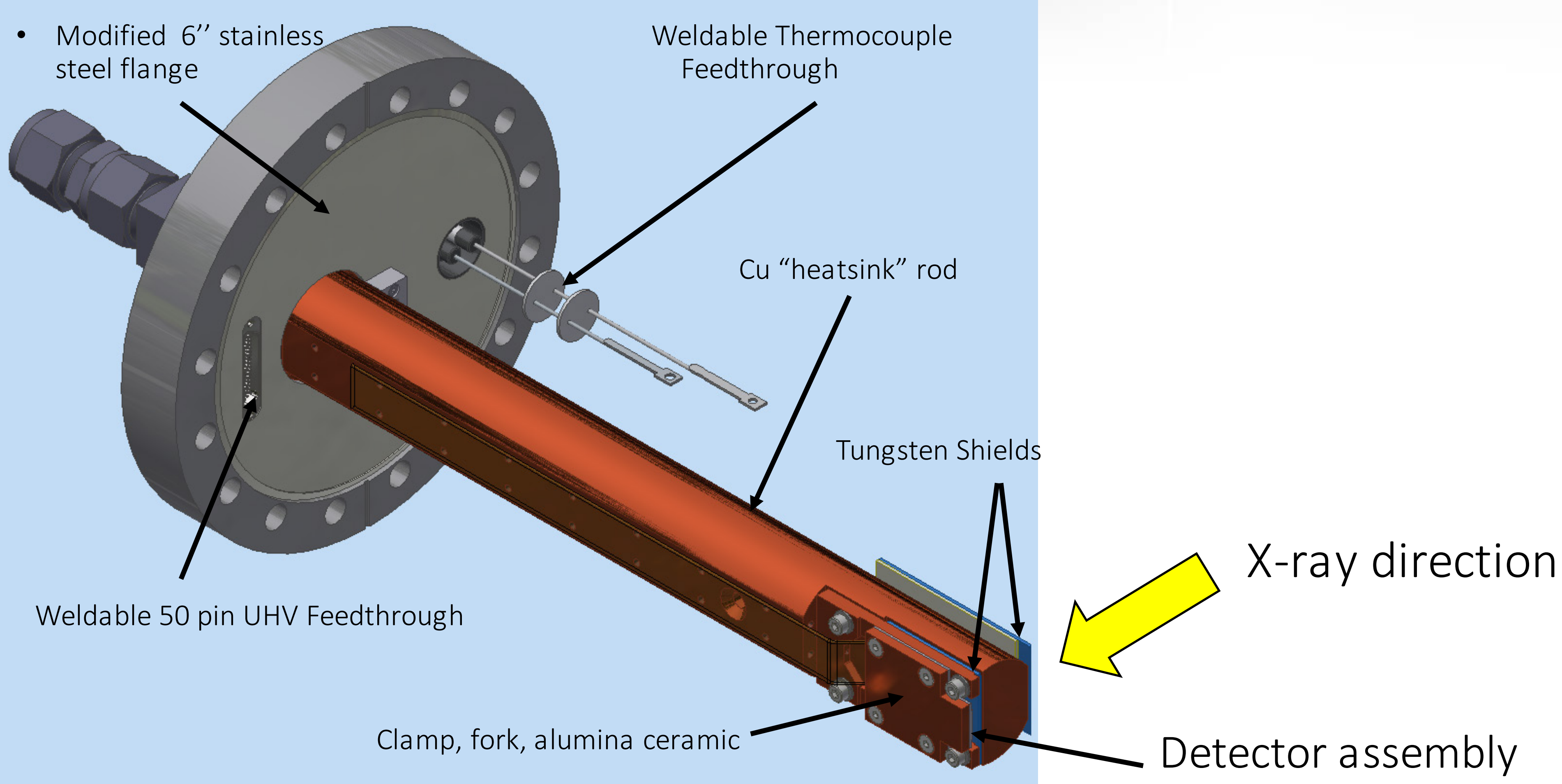
Vacuum Envelope Installation: completed



23-ID FOE
Apr. 26, 2022

Normal beamline ops resumed in May

To be installed shortly: Heatsink Assemblies with Detectors



Summary

- Non-invasive soft X-ray BPMs (sXBPMs) do not exist yet, but are greatly desired for coherent soft X-ray beamlines
- We are working to develop such sXBPM with micron-scale resolution for high-power white beams
- In our approach, multi-pixel GaAs detector arrays are placed into the outer portions of X-ray beam and beam position is inferred from the pixel photocurrents
- Unique needs of this application include sufficient detector responsivity from sub-keV to a few keV photon energies and the ability to handle large hard X-ray power densities, while producing manageable photo-currents. This was accomplished with our shallow p-on-n junction design.
- Detector array prototypes have been manufactured and extensively characterized with high-power Ar-ion laser, and then tested in soft- and hard X-ray beamlines of NSLS-II
- sXBPM prototype is to be installed and tested in the C23-ID First Optics Enclosure
- The bulk of the mechanical and vacuum hw installations was completed in May 2022 machine shutdown. The rest of the components are scheduled to be installed within the next few weeks
- We are looking forward to testing the sXBPM in high-power X-ray beam and demonstrating the desired device performance

Acknowledgements

Our project is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Accelerator & Detector Research Program of Scientific User Facilities Division. This research used beamlines 4-ID (ISR) and 23-ID-1 (CSX) of the NSLS-II, a DOE Office of Science User Facility operated for the DOE Office of Science by Brookhaven National Laboratory under Contract No. DE-SC0012704.