# Optics and instrumentation upgrades for resonant scattering and diffraction research at beamline 6-ID

This proposal presents plans for enhancing the capabilities of the 6-ID beamline. This beamline focuses on research in the areas of resonant and non-resonant diffraction, emphasizing the study of structural, electronic and magnetic phase transitions in single crystal and thin film condensed matter systems. The proposal includes upgrades to beamline optics (mirrors and monochromator) and insertion device to provide higher flux, stability and focusing, new instrumentation to provide enhanced low-temperature, high-pressure, and high electric and magnetic field capabilities, and the replacement of aging infrastructure.

## Scientific Justification

Over the past 20 years x-ray scattering techniques have played an increasingly important role in the study of complex magnetic materials. The power of x-ray probes lie in their unique elemental selectivity, polarization properties, time structure, and small beam size. Each of these characteristics can be used not only probe a materials magnetic state, but also its related charge, orbital, and structural degrees of freedom. How the interplay amongst these degrees of freedom lead to the lowest energy state (e.g. antiferromagnetic insulator, metal, superconductor, etc.) in materials such as complex oxides is currently a topic of intense interest in contemporary condensed mater physics research. X-ray studies have played a central role in understanding how such systems respond as they are driven through phase transitions between these different ground states via temperature dependence or more recently the application of external pump fields (e.g. magnetic, electronic, or photonic).

X-ray scattering techniques will continue to play a key role in condensed matter physics and materials science over the next 10 years. *New opportunities for significant scientific impact are envisioned to be in matter subjected to extremes of thermodynamic conditions.* Novel instrumentation and beamline capabilities will need to be developed to study materials using high pressure, high magnetic fields (pulsed and static), low-temperature, and other external parameters such as electric field. These key fundamental control parameters can be used to tune in novel states of matter that are crucial for developing a correct understanding of properties of materials. Further, *increasing attention will focus on how these properties can differ in quantum-confined systems such as artificial heterostructures and thin films*. The behavior of such systems becomes especially interesting near the broken symmetry of a surface or interface. The combination of high-resolution and diffuse x-ray scattering measurements can be used to extract critical parameters concerning the strain fields present at such interfaces due to lattice mismatch, temperature dependent phase transitions, or chemical intermixing. Deciphering how the long-range structural order induced by such strain is related to the observed macroscopic magnetic and transport properties is critical in order to utilize these materials for new device applications.

A third generation x-ray source such as the Advanced Photon Source provides an ideal facility for the such studies of magnetic, orbital, and structural effects on tiny samples with unprecedented resolution and sensitivity. Applying x-ray techniques, however, requires a highly focused stable x-ray source, such as that provided by upgrades detailed below.

## Added Value of the Mid-term Upgrade

The improvements detailed in this proposal will make this beamline a world-class state-of-the-art facility for single crystal and thin film diffraction measurements. Further, they would also provide greatly enhanced capabilities for the other programs (UHV surface scattering) that are also currently supported on this beamline. The improved focusing provided by the new mirrors, in particular, will help facilitate cutting-edge experiments, such as in-field and high-pressure magnetic scattering.

- *Optics upgrades to improve focusing*

Currently the 6-ID-B beam line provides only vertical focusing, which greatly restricts the possible types of experiments. Furthermore, the optical design contains only a single mirror vertically reflecting which yields an inclined beam, which is incompatible with horizontal scattering plane experiments, such as those involving high-field magnets. We envision the installation of two mirrors, one toroidal ($300k) and the other flat ($100k), in a mini-enclosure ($125k) just upstream of the 6-ID-B experimental station. This would provide an ~50x100 $\mu m^2$ horizontal beam in either of the experimental stations downstream. Such a beam would permit both high-field and high-pressure magnetic studies and dramatically enhance the capabilities for surface x-ray scattering studies (> x10 flux density enhancement) both on the psi-diffractometer in the 6-ID-B station and the UHV instrument currently located in the 6-ID-C station. In addition, a new set of monochromatic slits ($50k) would be installed in the mini-enclosure just after the mirrors to define the beam and reduce background radiation in the experimental station.

- *New sample environments and detectors*

The development of new sample environments is essential for the beamline to remain relevant to problems of current interest. To this end, we are seeking to provide new low-temperature, high-pressure, and high-magnetic field capabilities. For lower temperatures, we would like to procure a closed cycle He-3 cryostat ($150k) capable of accessing temperatures below 1K with much higher cooling capacity. The ability to remove heat from the system is a critical factor for x-ray experiments since the heat input from the beam itself limits the achievable base temperature. Similarly, a high-cooling capacity is required to enable high-pressure studies at extremely low temperatures. Diamond anvil cells with *in-situ* pressure application suitable for such applications are currently under development, but are thus-far limited to temperatures above 6K due to insufficient cooling capabilities. Furthermore, an additional proposal has been submitted to develop high-magnetic field (pulsed and static) capabilities for scattering and spectroscopy studies.

Two-dimensional detectors are playing an increasingly important role in diffraction measurements by measuring large cuts through reciprocal space quickly and efficiently. Such detectors can be used to probe in a time-resolved manner how long-range correlations induced by strain in thin films evolve. We proposed to acquire two detectors for such studies, a fast CCD camera ($100k) for lower energy work and a large-area amorphous Si detector ($170k) for higher energy applications.

- *Additional insertion device*

  Many scattering experiments involve the detection of very weak magnetic or structural modulation peaks, therefore they require the highest possible incident intensity. To accomplish this goal, we propose to expand the straight section 6-ID to 8 meters and install an additional insertion device ($300k). The new device would have a lower period than the currently installed undulator A (3.3cm). By limiting the lower energy range of the new device, significantly higher photon fluxes could be achieved in the area of most resonances of interest (6 to 12 keV) with lower heat loads on the beamline optics. Further, if even more flux is required this device could be operated in series with the current device.

- *New monochromator*

  The current high-heat-load monochromator is designed such that the cryogenic cooling lines enter through fixed ports located around the circumference of the monochromator. More recent monochromator models have on-axis cryogenic feedthroughs that rotate with the main goniometers stage. This prevents ‘tugging’ on the crystal mounts, which can cause pitch and yaw errors during a change in energy. Furthermore, the present monochromator employs an “after-market” designed Compton shield. With the envisioned increase in beam operating current to 200 mA and possible addition of a second insertion device, the enhanced heat load on this optic will need to be mitigated. Therefore we are proposing the replacement of the entire monochromator assembly.

- *6-ID-D High Energy Side-station*

  The 6-ID-D side station operates parasitically to the main branch using a transmission monochromator, which provides x-rays in the energy range between 30 and 120keV. High-energy x-rays provide an excellent probe for materials subjected to extreme conditions such as high magnetic fields, high pressure, or electrostatic levitation, since such environments typically have limited optical access to the sample. We envision expanding the capabilities of this experimental station in these areas in the future, in order to tie in more closely with the scientific mission of the rest of the sector. While no major improvements to either the source or optics for this station are requested at this time, future enhancements could be envisioned as the user community for such experiments develops.

- *Experimental control area enclosure*

  The current working environment on the experimental hall floor is not ideal for an APS user due to the significant ambient noise from a number sources. We propose to build an experimental control area enclosure for each of the end-stations on the beamline ($200k). This would create a much more pleasant reduced-noise working space for the user from which to conduct an experiment.

- *Replacement of aging infrastructure*

  There have been minimal capital investments in this beam line since its construction over 10 years ago. Therefore several beamline subsystems are in critical need of replacement. Specifically, the currently installed beamline controls ($50K) and EPS systems ($50K) are not supported by either AES group responsible for the maintenance of these systems. Therefore we propose to replace the current hardware and computers with versions more consistent with those found on other XOR beamlines in order to take advantage of the centralized support offered by the APS.

**Expected user communities**

Single crystal x-ray scattering is a well-established technique, therefore the upgraded beamline is expected to serve users from broad range of institutions and disciplines. While many of these users would come from the current user base of 6-ID, the proposed enhanced capabilities in the areas of low-temperatures, high-pressure and high-field would attract additional users from other areas in physics such as quantum phase transitions and heavy-Fermion research. Furthermore, there is a critical need for a general-purpose diffraction instrument at the APS. As beamlines at the APS have become more specialized, such capabilities have been cutback or removed on other beamlines. A psi-diffractometer optimized for resonant and non-resonant magnetic studies provides an ideal instrument for other types of diffraction studies on single crystals or thin films.

**Enabling technologies and infrastructure**

- Toroidal focusing and flat deflecting mirror
- Lower period insertion device
- High heat load monochromator
- Low temperature $^3$He cryostat

**Partnerships and user interest**

Prof. A.I. Goldman, Dept. of Physics and Astronomy, Iowa State University.
Prof Dr. Thomas Brückel, Inst. für Festkoerperforschung, Jülich, Germany.
Dr. Andreas Kreysig, Ames Laboratory
Prof. P. Maceli, Dept. of Physics, University of Missouri
Prof. E. Conrad, Dept. of Physics, Georgia Institute of Technology
Prof. S. Kumar, Dept. of Physics, Kent State University
Dr. Manuel Angst, Oak Ridge National Laboratory
Prof. Jak Chakhalian, Dept. of Physics, University of Arkansas
Prof. Thomas Rosenbaum, Dept. of Physics, University of Chicago

**Budgetary profile**

| | | |
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| Additional lower period insertion device | | $ 300k |
| New high-heat load monochromator with on axis cooling | | $ 350k |
| Mirror Enhancements | | |
| Mini-enclosure for mirrors/slits | $125k | |

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| Focusing mirror replacement | $300k | |
| Flat deflecting mirror | $100k | |
| In-vacuum monochromatic slits | $ 50k | |
| | | $ 575k |
| Experimental control area enclosures | | $ 200k |
| Replacement of beamline computer and EPS systems | | $ 100k |
| New detectors | | |
| Fast CCD detector | $100k | |
| Amorphous-Si area detector | $170k | |
| | | $ 270k |
| Low-temperature (<1k) $^{3}He$ cryostat | | $ 150k |
| **Total:** | | **$1945k** |