XSD Detectors Group's Strategic Plan

Mission

The XSD Detectors group supports the detector needs of the APS community from a short-term and long-term perspective.

From the short-term or operational perspective, the Detectors group operates the APS Detector Pool, which provides support for commercial detectors and equipment, and makes them accessible to all beamlines. We provide technical detector advisory services in a variety of ways (e.g., market research, design reviews, etc.) to assist beamlines with detector purchases and best detector practices.

From a long-term perspective, the group's R&D activities are aimed at enabling unique detector capabilities not commercially available. In particular, we currently have four DOE-BES funded projects on energy-dispersive detectors (superconducting TESs and Germanium) and pixel array detectors (FASPAX and VIPIC).

Current state

Detector Pool

The XSD Detector Pool provides on-call technical support, expertise, and technical advisory services on detectors at the APS. This is accomplished in a number of ways. The Detector Pool supports a wide range of commercially available detectors, and an assortment of electronics and thermal stages. Typically, these are more expensive detectors (e.g., Pilatus, Vortex ME-4) where individual beamlines cannot afford or justify dedicated systems. By facilitating access to these expensive detectors through time-sharing, we are making extremely efficient use of resources. We also provide back-up support (i.e., drop-in spares) for dedicated beamline detectors in case of catastrophic failures. The Detector Pool also serves as the outlet to introduce new, cutting-edge commercial detectors to the entire APS community. We accelerate and facilitate early access to new detectors and electronics that come on the market (e.g., GE a-Si flat panels, Vortex ME-4, Pilatus, Pixirad CdTe, Xspress3). Finally, the group is a resident user at the Optics & Detectors Beamline at 1-BM with activities led by Detector Pool staff. We are developing detector testing/characterization capabilities. The core Detector Pool team members include APS staff members Christopher Piatak, Russell Woods and one vacant position.

Detector R&D

The group pursues R&D activities aimed at enabling unique detector capabilities not commercially available. As outlined in the 2012 DOE/BES report on x-ray detectors[1], there are many unmet detector needs for x-ray light sources. We have chosen to focus our efforts on two

[1] http://science.energy.gov/bes/news-and-resources/reports/

areas for detector R&D: energy-dispersive detectors and pixel detectors. Each development is linked to scientific strategic goals of the APS and leverages local detector initiatives (i.e., superconducting cosmology detectors at ANL/HEP/UChicago and ASIC development at Fermilab). In addition, we have formed a number of strategic collaborations with other DOE laboratories. This has enabled us to secure direct funding from DOE/BES/SUF program office.

The projects range from the development projects ("D") which are based on lower-risk technologies and mostly require engineering effort (e.g., Germanium strip detector and VIPIC) to the research projects ("R") where the technology is yet unproven and there is a risk that needs to be retired (e.g., superconducting detectors and FASPAX).

Energy-dispersive detectors

Superconducting energy-dispersive detectors ("R")
The improved brightness provided by the upgraded APS may allow high resolution emission spectroscopy techniques to become more routinely applicable for spectroscopic analyses[2]. The high energy resolution superconducting XRF detectors coupled with a high flux, reflective-mirror based nanobeam from the APS Upgrade, will allow chemical state determination for multiple elements simultaneously, without monochromator scanning, and analyses that are much less susceptible to radiation damage. The APS Detectors group is working to develop these high energy resolution superconducting XRF detectors. Starting in 2010, we began an R&D program on a superconducting technology called microwave kinetic inductance detectors (MKIDs). This program was supported by a DOE Early Career award and APS Operating funds. As of 2015, we have transitioned to a different but related technology, namely microwave SQUID multiplexing readout of transition-edge sensors. We currently have a joint DOE three-year grant with NIST and SLAC to mature this technology. The APS Detectors group's primary responsibility in this collaboration is to develop thick absorbers, microwave readout electronics and the cryogenic testing and integration of NIST TES arrays and SQUID multiplexers.

Our overall strategy for superconducting detectors includes short and long-term plans. In the short-term, the collaboration with NIST and SLAC is largely focused on increasing the pixel speed and total pixel number. We rely on our collaborators, who are world-leading developers of superconducting detectors, for both the SQUID multiplexers and the TES sensor arrays. These strong collaborators give us the best opportunity in the short-term to bring these detectors to the APS for widespread use. However, we see an opportunity to develop TES arrays tailored to the needs of the APS (e.g., for high-energy applications). This is why we are developing techniques for thick x-ray absorbers via electrodeposition. In addition, the energy resolution of the NIST TES arrays is limited to ~< 3eV. The limiting noise source of these detectors is thermal noise. Beyond the NIST/SLAC collaboration in a longer term view, we are looking to improve the energy resolution of these detectors. One way to improve the energy resolution is to use TES with lower transition temperatures (T_c); energy resolution scales linearly with temperature. The NIST TESs (Mo/Cu bilayers) have $T_c \sim 100$ mK. Since there are a number of x-ray science applications which would benefit from better energy resolution, we plan to pursue the

[2] "Early Science at the Upgraded Advanced Photon Source", August 2015

development of TESs with $T_c < 50$ mK. We have started preliminary work on Ir/Au TES bilayers which should be able to be tuned to these temperatures. Since these low T_c TESs are also of interest for HEP/Nuclear Physics applications, we plan to submit a joint LDRD with HEP/PHY/MSD divisions next year to develop these low T_c TESs.

The core team members include APS staff members: Thomas Cecil, Lisa Gades, Timothy Madden, and Antonino Miceli. In addition, an Applied Physics graduate student (Daikang Yan) from Northwestern University is working on a PhD thesis on superconducting detectors.

Germanium Strip Detector ("D")
A unique characteristic of the present APS among U.S. light sources is its high flux at high energy (>20 keV). After the upgrade, the APS will have significantly enhanced flux densities at high energies. To fully exploit this unique characteristic, we are developing Germanium detector arrays for high energy spectroscopic applications such as energy-dispersive and powder diffraction. In particular, we are combining the low-noise integrated circuits developed at BNL with commercially available segmented germanium detectors with excellent pixel-pixel isolation made by Semikon.

The core team members include APS staff members: Jonathan Baldwin, Antonino Miceli and Russell Woods.

Pixelated Detectors

FASPAX ("R")
The APS bunch pattern, with ~100 ps bunches separated by ~ 150 ns, is unique as a normal operations mode at 3rd generation synchrotron sources. The APS Upgrade presently plans to retain a bunch pattern allowing timing experiments in normal operations mode, 100 ps bunches separated by ~75 ns. A vibrant user community has developed at the APS which utilizes the APS bunch pattern. The development of fast frame detectors will help to retain and grow this strength. FASPAX (Fermi-Argonne Semi-conducting Pixel-Array X-ray detector) will be a fast integrating detector with wide dynamic range. FASPAX will use in-pixel analog storage to acquire a burst of > 50 images at a frame rate of 13 MHz. This frame rate will match the machine bunch rate of the standard timing mode of the upgraded storage ring. At top speed, the detector will enable single bunch imaging and allow access to the 100 ps temporal resolution achievable by the APS. User defined timing schemes (such as exponential or logarithmic timing intervals) will also be supported. Dynamic range is particularly challenging for charge integrating detectors. Unlike photon detectors, where dynamic range is determined simply by the size of the pixel counter, charge integrating detectors are typically limited in dynamic range by ASIC capacitor sizes. To overcome this dynamic range limitation, a unique current splitting integrator with three gain ranges will be used. The high gain branch will be sensitive to single photons, while the lowest gain branch will properly handle 10^5 x-rays in a single pixel. The appropriate gain will be chosen by the pixel logic according to the amount of integrated signal. FASPAX will handle much more instantaneous flux than any currently available photon counting area detector. Finally, FASPAX will prototype a new method to remove the gaps commonly found in pixel detectors. Wire bonds required for readout and

inactive control regions of the ASIC have mandated coverage gaps in detectors with sensors larger than a few centimeters. FASPAX will use a novel hybrid structure involving an interposer to eliminate coverage gaps. Made of glass or silicon, the interposer will reside between the sensor and ASICs. Vias through the interposer will allow connections between the ASICs and pixels in the sensor, while traces on the surface of the interposer will provide power and data readout to the ASICs, eliminating the need for wire bonds. The interposer will allow the pixel pitch to vary between the sensor and ASIC. A larger sensor pixel will provide coverage over the inactive portions of the ASIC.

This effort is currently supported through the APS Upgrade. The APS Detectors group is responsible for the sensor design, data acquisition and overall project management. Fermilab is responsible for the ASIC design. The core team members include APS staff members: Robert Bradford, Timothy Madden and Taylor Shin (post-doc).

VIPIC ("D")

The APS source after the upgrade will provide world leading beam coherence and high brightness which will enhance greatly experiments in XPCS, among other techniques. Thus to address the future needs of the XPCS user community, we have embarked on the development of pixel array detectors specifically designed for XPCS. The VIPIC (Vertically Integrated Photon Imaging Chip) detector incorporates several features optimized for XPCS:

1. Sparsified readout: The detector will only read out those pixels recording an x-ray hit during the integration window, greatly streamlining the data flow.
2. High temporal resolution: The simplified data stream permits high frame rates, while zero readout dead time will allow temporal resolution of better than 10 μs.
3. Real-time calculation of XPCS auto-correlation functions.

This project will develop mega-pixel scale detectors for beamline 8-ID at the APS and the CHX beamline at NSLS-2. The project will develop all required detector components, including the sensor, application specific integrated circuit (ASIC), back-end electronics, and full data acquisition system. Of major technical importance, the VIPIC ASIC being developed pioneers use of 3D integrated circuits in x-ray science.

This project builds upon an earlier effort by Brookhaven and Fermilab begun in 2008. That effort produced a small prototype detector (64 x 64 pixels), incorporating a small 3D ASIC. The prototype recorded XPCS data during 2 weeks of beamtime at 8-ID during the summer and fall of 2014. These beam tests successfully proved the VIPIC concepts for an expanded development effort.

Institutionally, Argonne joined the VIPIC collaboration for the present DOE/BES/SUF proposal in the summer of 2014, with responsibility for the data acquisition system and real-time auto-correlator. So far, effort for all institutions has focused on designing the basic detector components. At Argonne, the focus has been on prototyping the auto-correlator and designing the data acquisition components.

The core team members include APS staff members: Robert Bradford and John Weizeorick. (with guidance and support from Sector 8 XPCS beamline scientists)

Vision

Detector Pool

Over the next 3 years, we will continue to introduce cutting-edge detectors (e.g., Keck PAD from Cornell/Sydor, and detectors from the medical imaging market such as flat panel CMOS, CdTe). We will continue our advisory role for new detector acquisitions beyond the Detector Pool. We expect to assist the APS Upgrade in the evaluation and selection of detectors for new and refurbished beamlines. We will continue to develop testing characterization capabilities at 1-BM focused on evaluating commercial detectors for the Detector Pool and also support testing of internal detector R&D projects.

Detector R&D

Energy-dispersive detectors

Superconducting energy-dispersive detectors (“R”)
By end of FY17, we will demonstrate cryogenic multiplexing of at least 100 channels of fast, hard x-ray TES into a calorimeter array with < 3eV resolution and with performance metrics scalable to at least 100 kcps. At this point, we will have retired the key technological risks and we will set out on the design and construction of a kilopixel science detector to be deployed at an APS beamline. The design and specifications of the detector will be integrated into the design of the beamline. It is also possible to build a detector for general purpose use for the APS Detector Pool with a few beamlines as key stakeholders.

Germanium Strip Detector (“D”)
By the end of FY17, we plan to build several complete 1D strip detector systems, with up to 384 strips, for the APS and NSLS-2. Beyond this initial development of 1D detectors, we will investigate the feasibility of developing 2D pixel detectors with Germanium sensors.

Pixelated Detectors

FASPAX (“R”)
The basic pixel logic for the FASPAX will be established in two prototype ASICs submissions. Prototype sensors in both silicon and CdTe will be designed at APS. Silicon sensors will be fabricated by the Semiconductor Detector Development and Processing Lab at Brookhaven National Laboratory and a new commercial supplier (Novati), and CdTe sensors will be fabricated commercially. Functional prototypes (i.e., ASICs and sensors bump bonded together) will be tested with x-rays within 3 years, with an ultimate goal of mega-pixel scale detectors being delivered to the APS before completion of the storage ring upgrade. We envision future funding sources to include the APS Upgrade and the DOE/BES/SUF program office.

VIPIC ("D")
A prototype data acquisition system will be developed and tested with a single VIPIC-L chip. Three of these systems will be produced, one for each collaborating institution. Once successfully tested, the design with be scaled up to accommodate a full mega-pixel detector. Two of the large systems will be fabricated and deployed at APS and NSLS-2 before the completion of the APS Upgrade.

Future Plans/Strategy

Below we enumerate our future plans/strategy to sustain and grow the APS Detectors group.

1. We will plan for regular reviews of the Detectors Group (e.g., SAC and detector stakeholder reviews).
2. We will pursue capital investments for the Detector Pool.
3. We will search for new and novel commercial or semi-commercial detectors for the Detector Pool in order to provide early access of new detector technologies to the APS community.
4. We will communicate our progress with the local stakeholders and our sponsors on a regular basis.
5. We will advocate for investments in pixel detector infrastructure (i.e., probe station for sensor characterization (Silicon, CdTe, Ge)). This is particularly important since APS is responsible for the sensor design and testing for FASPAX.
6. We will advocate for investment in staffing. A new hire with semiconductor physics experience for detector sensor effort is a high priority in order to add depth to detector development effort. In addition we plan to incorporate graduate students in this work. We plan to continue to attract graduate students to work on detector R&D projects. The superconducting detector development has benefited from a graduate student from Northwestern University's Applied Physics program. The pixel detector R&D could benefit from graduate students as well.
7. We will continue to secure funding from DOE/BES/SUF and LDRDs to supplement the APS operations funding.

SWOT Analysis

Strengths	Weaknesses
• Versatile team with wide range of expertise • Extensive capabilities in Detector Pool (unique in the US) • Regular access to beamtime for detector testing at 1-BM • Strong collaborations	• Lack of policies and procedures to purchase and support beamline detectors. • Lack semiconductor expertise/staffing & measurement/characterization equipment • Tech transfer/licensing
Opportunities	**Threats**
• Grow the detector user community for 1-BM • Delivering unique detectors to the beamlines (e.g., superconducting, bunch-imaging pixel detectors, VIPIC, Germanium) • Strengthening synergies between super- and semi-conducting developments ANL-wide (e.g., fabrication, measurement) • Grow publication productivity • Grow/maintain outside funding sources	• Commercialization from competing detector groups (e.g., Europe, SLAC, Cornell) • Dependence on outside collaborators for critical milestones • Potential for shrinking budgets could impede progress