Synchrotron Radiation Detector Roadmap

Version 1.6

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Introduction

This report contains the ideas for the short, medium and long-term detector requirements for the exploitation of synchrotron radiation. This report maps the detector requirements identified by the SR users at the meeting in Manchester (Palace Hotel March 2001) and the technologies currently available. The short and medium term developments concentrate on what is available to the UK communities now. The longer-term developments may require international collaboration with SR sources such as the SLS or with development groups in the disciplines associated with astrophysics. The report aims to extract the developments that would have a major impact and develop synergies between research areas. This is particularly true where technologies have been identified that can be used in several science areas.
This report contains recommendations that could be adopted and built on for a wide ranging detector programme that would be of benefit to the SRS, DIAMOND and any other 4th Generation Light Source proposed for the UK.

Summary of Document in tabular form

Science Area	Short Term (1-2 years)	Medium Term (2-4 years)	Longer Term (5years plus)
Spectroscopy	Buy Commercial XAFS STRIP detectors IMPRESS	Hybrid Pixel Detector IMPRESS	Hybrid Pixel detectors APS Cryogenic Detectors
Diffraction	HOTWAXS, GMSD2D DIFFEX	Multiple DIFFEX APS for PX	3D detectors APS
IR	Materials trials	IRSTRIP	IRIMAGE APS STREAK
UV	Materials trials	UVSTRIP	UVIMAGE APS STREAK
Electrons	REES(ELECSTRIP)	ELECSTRIP ELECTIMAGE (APS trials)	ELECIMAGE APS STREAK
Soft X-ray	XMCD (GMSD)	APS	APS

Generic requirements

- **Data acquisition**

The requirement for a reusable open-architecture data acquisition system underpins all detector development. Some of this system is already under development for particle physics, however specific requirements such as time stamping and continuous data flow will be necessary. For example the data acquisition requirements of development systems or lower rate detectors can be met by 'Generic DAQ' cards developed for general purpose use. The cards have an industry standard format and PCI output bus that allows them to be plugged into commercial VME processor modules or into PCs. Each card incorporates 256 Mbytes of memory and two Altera

10KE30 Field Programmable Gate Arrays for data buffering and processing. Plug in front end cards have either 68 bi-directional LVDS digital channels or eight, 12 bit, 50MHz Analogue to Digital Converters. The Generic DAQ cards were designed to be built into scaleable systems and the requirements of more demanding applications, such as high rate pixel detectors, could be met by using larger numbers of cards. However this would not be the most efficient solution. The next generation of FPGA circuits offer features such as built in Power PC processors and 3 Gbit/s serial I/O that would dramatically increase the capacity of the data acquisition system. These devices open up new opportunities in data acquisition architecture including high speed serial data transmission from highly integrated front end circuits, real time data analysis, and integration with the beamline control and sample environment systems in high throughput or dynamic experiments.

- **Imaging and spectroscopy.**

There are several areas that have underpinning detector technology requirements. These are identified under the scientific areas that follow. There is also a clear trend towards area detectors with energy resolution that can register a 2-D image of a material combined with spectroscopic or structural information at each pixel.

- **Energy resolution**

In many applications 1keV FWHM would be sufficient to eliminate harmonics, scatter and other artefacts. In more specific applications that require spectroscopy 250eV FWHM will be required for spectral line identification.

- **Count rate**

The high fluxes of the 3rd generation sources dictate we need to handle 10^8 photons /cm^2 with a spatial resolution approaching 150um for X-ray systems.

- **Efficiency**

While protein crystallography is centred about 12keV much of the engineering work requires higher energies to penetrate samples. We require at least 50% efficiency out to 150keV with minimal dead time introduced by the instrument itself. Additionally there should be only 1-2 pixel equivalent dead-regions on the detection area. This will allow effective image construction with image post-processing.

Medium term Developments and Costs

Following a meeting of technical specialists at the Coesners House Abingdon in December 2001 a selection was made of the best match of existing detector technologies to the medium term user requirements. These developments would also form significant building blocks for the longer-term detector needs. The short term, immediate needs appear with the science user group cases that follow.

Technique Area	Development	Approx. Costs
Spectroscopy	Hybrid Pixel Detector	£1,500k
Diffraction	Hybrid Pixel Detector	£1,500k
Ultra Violet	UVSTRIP	£500k +£250k (£250k materials work)
Infrared	IRSTRIP	£500k
Electron	ELECSTRIP ELECIMAGE	£500k (MCP replacement work) £1,500k (image readout)

Spectroscopy

- **XAS detectors - short term**

Compact Germanium detectors are now an accepted way forward and the compact monolithic design is beginning to deliver detectors that can, with appropriate readout electronics, handle the flux concentration from focussing optics. The requirement in this area is for detectors that work at high rate with a reasonable number of channels

There is an immediate proposal to upgrade station 9.3 with compact Germanium detector and with XSPRESS2. XSPRESS2 will use higher rate ADCs and new FPGA technology. Estimates for a 16 channel C-TRAIN and a new XSPRESS system. XSPRESS may be best approached with a joint proposal with the Nuclear Physics community (IMPRESS) that will use similar approach to XSPRESS
Hardware £200k effort 0.5 to 1.0 Staff years. Can be achieved in 12 months (or less)
This upgrade (in partnership with industry) would work to reduce the cost per system by using CLRC intellectual property to offset costs of detectors bought from ORTEC through technology transfer.

XMCD Gas microstrip detectors can be used for X-ray Magnetic Circular dichroism and soft X-ray. This project would be achievable in less than 18 months with already proven technology.

- **XAS detectors - medium term.**

A highly pixelated compact detector based on output from the IMPACT programme funded by Technology Foresight programme has proven this technology. The development of these detectors will be concentrated in the 10keV to 200keV.

These detectors would have to operate at room temperature and have sufficient throughput rate to be used as very close to sample detectors. Option would include detectors that could be easily moved around with the fluorescence radiation close to a sample. For example, to avoid diffraction peaks, or to be quickly moved away from the sample area when a diffraction pattern is required. The hybrid pixelated detector approach allows for the detection medium to be Si, GaAs or CZT depending on the energy range that is required.

The project will be costed in a similar way to SHAMROC to give greater detector flexibility. The readout system will be developed for ease of use.

- **XAS detectors - longer Term**

More compact readout with three side butting to allow tiling would be the next step. The readout chips would need significant redesign potentially with ADCs on chip. This development would make use of the already funded PPARC work in this area in compact hybrid detectors

Science drivers for higher spectral resolution detectors that are capable of measuring edge shifts in fluorescence energy are now being addressed by new detectors that will have sub 10 eV resolution. These detectors are available in a low channel number configuration using either Transition Edge Sensors or Superconducting Quantum Tunnel Junctions. The United States SR biological spectroscopy community are actively pursuing these detectors with transfers of technology from Space applications. Within the UK a similar opportunity exists. This is being pursued under the Basic Technology Funding proposal however if this is not successful another way of funding needs to be found. Not only must the detectors be made to have a higher throughput, probably by developing higher number of pixels per detector but also the cryogenic electronics and the interface electronics to a normal temperature environment.

Diffraction

- **Diffraction - short term**

Many scattering detectors are based on the RAPID interpolation system. The detector itself is based on a microgap wire detector. The ease of manufacture could be improved by replacing the wire planes with microstrips. Gas microstrips will also be necessary where high-count rate and medium angular resolution are required. Gas microstrips and solid-state strip detectors will naturally replace wire detectors in the future and a high level of support should be given to facilitate these developments through specific short-term development proposals. Thus far RAL is the centre of excellence in this technology and this resource should be fully utilised

The DIFFEX Prototype is a photon counting detector based on a silicon strip design. As a concept DIFFEX carries on from the preliminary work carried out at Daresbury with University of Glasgow and the output of the IMPACT programme. The parts for DIFFEX were developed by CCLRC through internal funding but now need specific funding to be engineered for use on an SR diffraction station. Longer term the development of DIFFEX will be combined with the development of 3-dimensional semiconductor detectors that will allow the detection of higher energy X-rays with high efficiency and excellent spatial resolution. DIFFEX detector electronics could be combined with HOTWAXS (High Overall Throughput Technology Wide Angle X-ray Scattering) to give a compact detector electronics system.

Specifically designed fast scintillation detectors to receive the output from multiple analyser assemblies will be necessary. This is a short-term project requiring very little development.

- **Diffraction - medium term**

A large angle coverage detector for Diffraction could be built which covers 120^0. This would comprise several DIFFEX tiles that would need redesign in order to minimise dead area between tiles. We may collaborate with the Swiss light source in this area.

A detector based on bump bonding with 1.5 dimension would be very useful for obtaining more information about the homogeneity of the diffraction pattern. This could be developed from the basic building blocks for a 2 dimensional detector that would follow in the longer term.

All these activities track the development of new materials such as CZT, GaAs, or HgI for high-energy work. Additional support will be needed to utilise the latest materials in out applications. This would be required for SRS and Diamond.

- **Diffraction - long term**

Longer term would require development of area detectors similar to IMPACT. Hybrid pixellated detectors with 100 μ

Please note that for Energy Dispersive Diffraction use refer to the sections on spectroscopy and TEDDI detectors. Their use in diffraction will be equally widespread.

UV

- **UV - short term**

A programme to apply silicon technology to circular dichroism has already begun. This technology will eventually replace photomultiplier tube technology. The UK has a lead in this area. An excellent short-term development would be to build a linear array readout system based on XSTRIP readout technology. To increase the spectral response in the UV area of the spectrum other materials than Silicon need to be evaluated such as GaN, SiC and diamond.
These linear arrays could use XCHIP type readout with a standard DAQ system.

- **UV - medium term**

In the medium term we need to develop larger numbers of channels with the SiC, diamond and GaN materials for stopped-flow measurements. Also flow measurements will be possible while sweeping the photon wavelengths. Multi strip systems could allow reduction of experiment time but the long-term development is needed.

- **UV - longer term**

An imaging detector developed from a linear detector and readout would be of exceptional use. This will enable combined measurement using the flow technique in one dimension while simultaneously measuring all relevant wavelengths in the second. This will allow for the first time to see chemical reactions progressing down the tube and dynamically changing reaction conditions.

IR

- **IR - short term**

Develop a higher density linear array readout based on XSTRIP technology.
These linear arrays could use XCHIP type readout with a standard DAQ system and this would replace the previous version of HX2 used on CLF.

- **IR - medium term**

Medium term will need the development of higher number of channels and eventually head towards imaging techniques.

- **IR - Longer term**

An area IR detection system over an extended range would be the ultimate goal of the IR community coupled with excellent timing resolution.

Electrons

- **Electrons - short term**

Linear arrays such as REES will be developed however the limiting factor is the MCP. There is an urgent need to develop an MCP equivalent that would give significant increase in throughput for electron amplification. An evaluation of MCPs and relevant technologies has been undertaken by CCLRC through its Centre for Instrumentation. The output from this investigation will show the way forward with electron amplification techniques.

- **Electrons - medium term**

Direct detection of electrons in to a MAPS device may be possible. An area detector could be developed medium term and this would be required to be developed longer term to a high time resolved detector system which was not limited by microchannel plates.

- **Electrons - longer term**

A MAPS solution may be the solution but needs to be investigated in detail as to the damage that electrons give to particular MAPS devices. If the basic technology funding of MAPS is not forthcoming this is an area that must be investigated specifically for Synchrotron Radiation. If a MAPS solution is not possible then an imaging electron detector will be required which can be built upon the linear detectors proposed in such EPSRC funded developments as REES.

Soft X-ray

- **Soft-X-ray - short term**

It would be attractive to extend this XMCD technique below 500eV. At present this can only be done with electron yield measurements in vacuum. Unfortunately XMCD requires high magnetic field (>1T) that render electron yield impossible. Gas Micro Strip Detectors have been shown by DL to work down to 500eV with conventional windows for Magnetic Circular Dichroism. Below this very sophisticated windows will be needed and close control of gas performance and dead layer thickness. This is a useful approach in the short term.

- **Soft X-ray - medium term**

Gas detectors will always require a window to separate the 1bar active gas from the vacuum. A back illuminated Monolithic Active Pixel Sensor may be an appropriate approach where integrated flux is sufficient. Typically only 10kHz of interesting photons are generated in the technique. CCD and Silicon Drift Detectors have demonstrated efficiency at very low energies. Published data shows efficiency below 200eV. There is also the attractive development of Active Pixel Sensors on either high or low resistivity Silicon. This would give low energy efficiency and flexible readout.

- Soft X-ray - long term

Long term it is likely that cryogenic developments using STJs and Transition Edge Detectors will improve throughput rate and give a large number of pixels with excellent spectral and spatial resolution. This is achieving 10-20eV resolution in this range and gives good spectroscopy into the UV and below.

Glossary of terms

ADC	**Analogue to Digital Converter**
APS	**Active Pixel Sensor (also MAPS)**
CLF	**Central Laser Facility**
C-TRAIN	**Germanium detector for spectroscopy**
CZT	**Cadmium Zinc Telluride**
DAQ	**Data Acquisition System**
DIFFEX	**One dimensional diffraction strip detector**
FPGA	**Field Programmable Gate Array**
FWHM	**Full Width Half Maximum**
GaAs	**Gallium Arsenide**
GaN	**Gallium Nitride**
GMSD	**Gas (Glass) Micro Strip Detector**
HgI	**Mercuric Iodide**
HOTWAXS	**High overall Through-put Wide angle X-ray Scattering Detector**
HX2	**128 channel Integrating readout chip for strip detectors**
IMPRESS	**I**ntegrated **M**ultichannel **P**reamplifier & **R**eadout **E**lectronics for **S**egmented **S**ensors
IR	**Infrared**
LVDS	**Low Voltage Differential Signals**
MAPS	**Monolithic Active Pixel Sensor (silicon detector with integrated electronics)**
MCP	**Micro Channel Plate**
RAPID	**Multiwire fast Gas detector system**
REES	**Real Time Electron Energy Spectroscopy**
SHAMROC	**SHaper and Read Out Chip**
SiC	**Silicon Carbide**
SLS	**Swiss Light Source**
SRS	**Synchrotron Radiation Source (Daresbury Laboratory)**
TEDDI	**Tomographic Energy Dispersive Diffraction Imaging**
UV	**Ultra Violet**
XAFS	**X-ray Absorption Fine Structure**
XAS	**X-ray Absorption Spectroscopy**
XCHIP	**Chip for XSTRIP**
XMCD	**X-ray Magnetic Circular Dichroism**
XSPRESS	**X-ray Signal Processing Electronics for Solid State detectors**
XSTRIP	**1024 channel silicon detector for energy dispersive detection**