Xspress3 Epics Driver with areaDetector 3

Matthew Newville, GSECARS, The University of Chicago, APS beamline 13-ID-E.

Matthew Pearson, Nick Rees, Adam Bark (Diamond Light Source, formerly)
Matthew Moore (APS, formerly)
Mark Rivers, Tony Lanzirotti (GSECARS)
Liam O'Ryan (Quantum Detectors)

Quantum Detector's XSPress3 electronics provide high-throughput pulse-processing for X-ray fluorescence spectroscopy detectors.

The Epics interface uses Epics areaDetector (AD) and has a complex history:

~2012: M. Pearson used Epics AD (v1) - a great idea. But AD v1 is missing some features. The MCA ROIs are pretty kludgy. Then left DLS. Epics code at DLS goes through several "owners". All have left DLS.

~2014: We (and several others) began using Xspress3 with this epics support from DLS, shipped by QD.

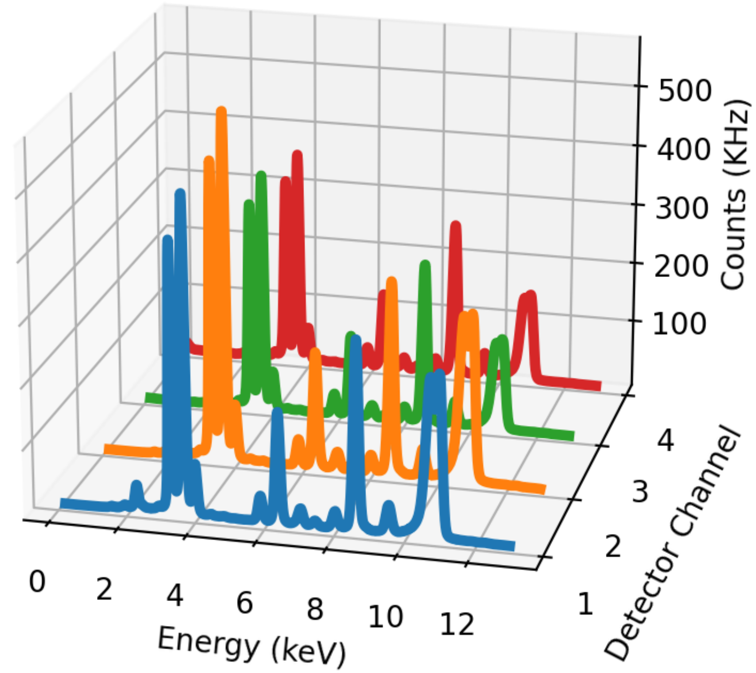
~2015: M. Moore modifies IOCs to use epics AD2 and especially the ROIStats plugin. Then left APS. Code now on GitHub epics-modules, using AD3. Used many places, but neither DLS nor QD use this code.

6-Oct-2020 these slides: https://tinyurl.com/xspress3oct20

Using areaDetector for spectroscopy electronics

The spectroscopist will think about a 4 (or even 16) element XRF detector as a set of separate MCA spectra:

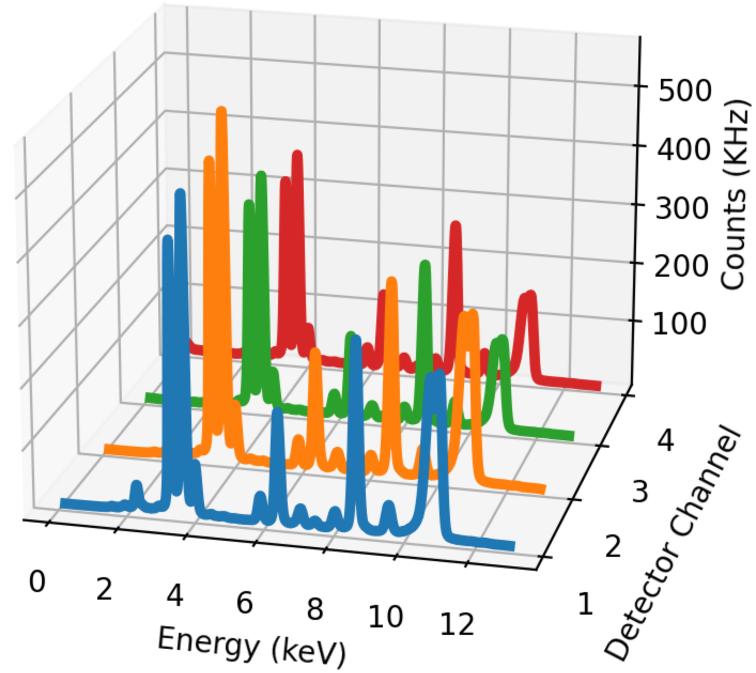
4 MCA spectra, each with 4096 energy points at 10eV spacing. They will add spectra together in post-processing - sometimes one might be tossed out.



Using areaDetector for spectroscopy electronics

The spectroscopist will think about a 4 (or even 16) element XRF detector as a set of separate MCA spectra:

4 MCA spectra, each with 4096 energy points at 10eV spacing. They will add spectra together in post-processing - sometimes one might be tossed out.



But the data is just a very oblong Area Detector - a 4 x 4096 array of data:

Channel

0	1	2	1	3	12	19	32	22	13	9	4	3	3	2	1	0	1
0	2	3	4	4	15	23	37	24	15	11	6	2	5	4	2	1	2
0	0	5	2	5	11	21	29	18	12	8	3	1	5	3	1	1	0
0	3	8	6	3	14	17	30	26	16	7	5	2	3	2	2	0	1

Energy bin

If the detector gives an 4x4096 "image" array, then areaDetector already does nearly all of the work for extracting and using these data.

areaDetector plugins for Xspress3

The Xspress3 driver does return an Ndet X Nenergy (4x4096) array for each detector "image": the full spectrum for each time step.

0	1	2	1	3	12	19	32	22	13	9	4	3	3	2	1	0	1
0	2	3	4	4	15	23	37	24	15	11	6	2	5	4	2	1	2
0	0	5	2	5	11	21	29	18	12	8	3	1	5	3	1	1	0
0	3	8	6	3	14	17	30	26	16	7	5	2	3	2	2	0	1

HDF5 Plugin: stream series of images to file.
Process Plugin: adds single "images" to summed "images".
ROI Plugin: split (Ndet x Nenergy) "images" to Ndet separate (1 x Nenergy) arrays for both single spectrum and summed spectrum.
→ the instant and accumulated spectra for each detector element.
ROIStats Plugin: MCA-like ROIs (named energy ranges) from individual spectrum with TimeSeries of "total counts" or other statistics.

The detector also reports 10 scalar statistics for each "image", including:
ClockTicks (real time in 12.5nsec bins),
Number of Resets, ***All Events***, ***Good Events,***
Deadtime Factor, ***Percent DeadTime***

These "SCA"s will all be saved in HDF5 files and can be streamed as TimeSeries.

Xspress3 Epics Driver with areaDetector 3

QD ships epics support using AD1.9 (AD2.0 was released in April 2014) while the code (current version = 3.2.5) at
https://github.com/epics-modules/xspress3)

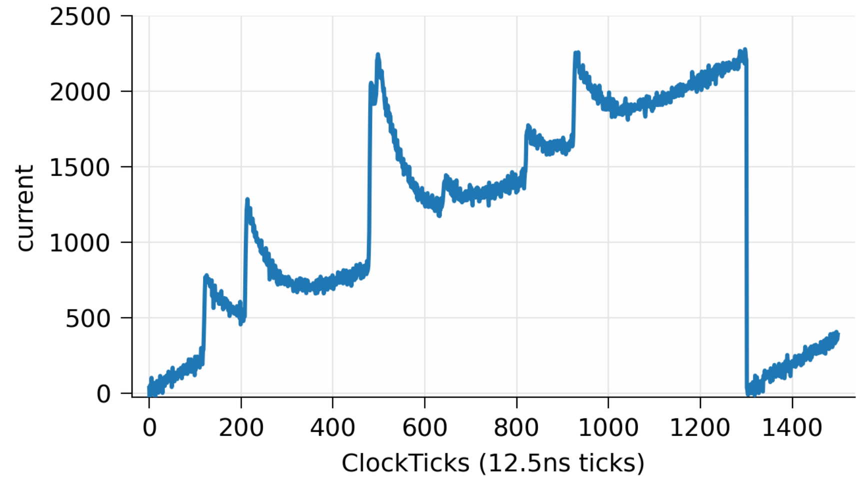
use the latest version of AD and tries to follow modern epics standards. Yes, we have talked with QD and DLS many times about how to merge code.

Main improvements in the Xspress3 AD2/3 version:

- Mapping mode: triggered streaming of full spectra to HDF5 files. Available in AD1.9 version, but with several bug fixes from AD3+.
- ROI mode: triggered streaming of up to 48 selected MCA ROIs using ROIStats plugin, not available in AD1.9.
- Improved deadtime corrections: save uncorrected spectra and the multiplicative factor needed for correction in post-processing.
- Display manager screens for medm, edm, caqdtm, css, and phoebus.
- Python XRF display and simple control application.
- Easy-to-install standalone version (from single build script) for those who want to use on the QD-supplied linux box.

Deadtime calculations for Xspress3

The Xspress3 digitizes the current on each channel onto 12.5 ns time samples and tries to detect and measure the intensity of each pulse as well as it can.



Among the statistics reported are:

ClockTicks	Real Time (in clock ticks)
ResetTicks	Flushing of leakage current.
AllEvents	Detected Events (output counts)

The detection and processing for each event takes some minimum time – an ***EventWidth*** so that the recommend way of estimating LiveTime is

LiveTime = ClockTicks – (AllEvents * EventWidth + ResetTicks)

EventWidth will be ~ 5–10 clock ticks (75 to 125 ns) and may vary with detector channel. It is sort of an intrinsic "rise time".

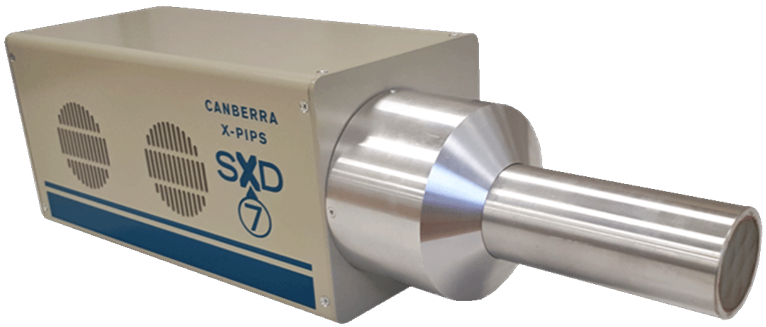
The deadtime correction is then

DT Factor = ClockTicks / (ClockTicks – (AllEvents*EventWidth + ResetTicks)

EventWidth can be set as Epics PV at run time to control the Deadtime calculation.

Xspress3 example data: testing Canberra SXD-7 SDD

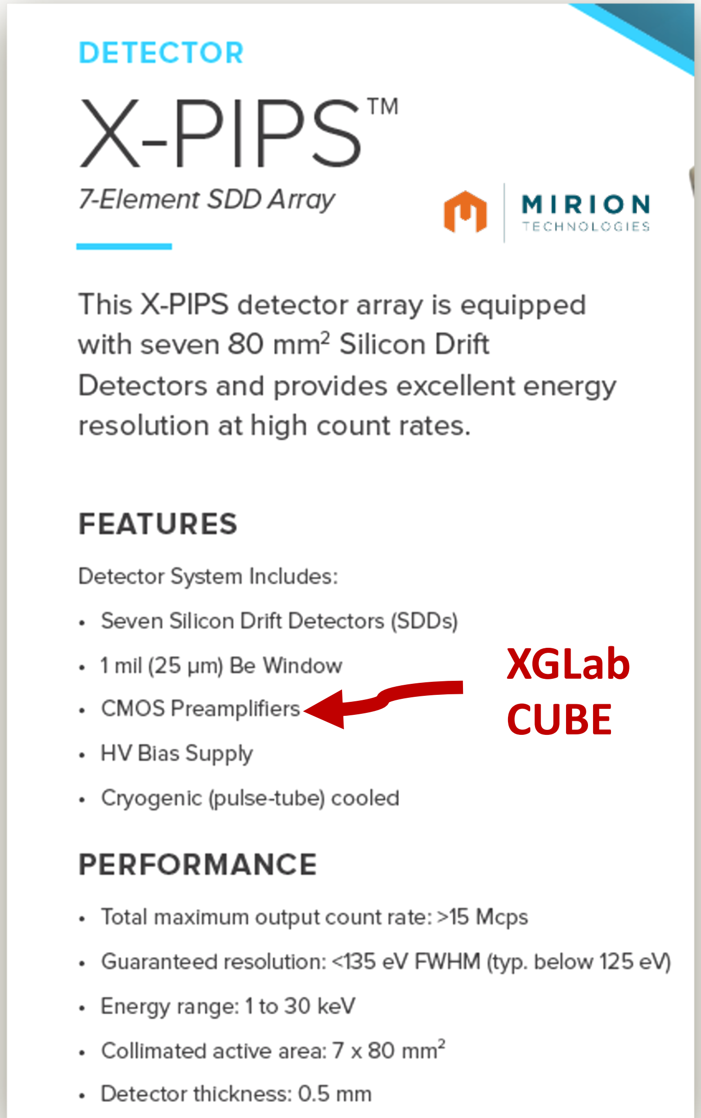
Xspress3 tests with Mirion/Canberra X-PIPS 7-element silicon drift diode array.



The detector runs at -80° C, using Canberra's Cryo-Pulse pump and controller.

Detector arrived at GSECARS March 3rd, 2020
Performance tests done a few days later:

Peak resolution (FWHM)
Total count rate
Dead-time curves


DETECTOR

X-PIPS™

7-Element SDD Array

MIRION TECHNOLOGIES

This X-PIPS detector array is equipped with seven 80 mm² Silicon Drift Detectors and provides excellent energy resolution at high count rates.

FEATURES

Detector System Includes:

- Seven Silicon Drift Detectors (SDDs)
- 1 mil (25 μm) Be Window
- CMOS Preamplifiers
- HV Bias Supply
- Cryogenic (pulse-tube) cooled

PERFORMANCE

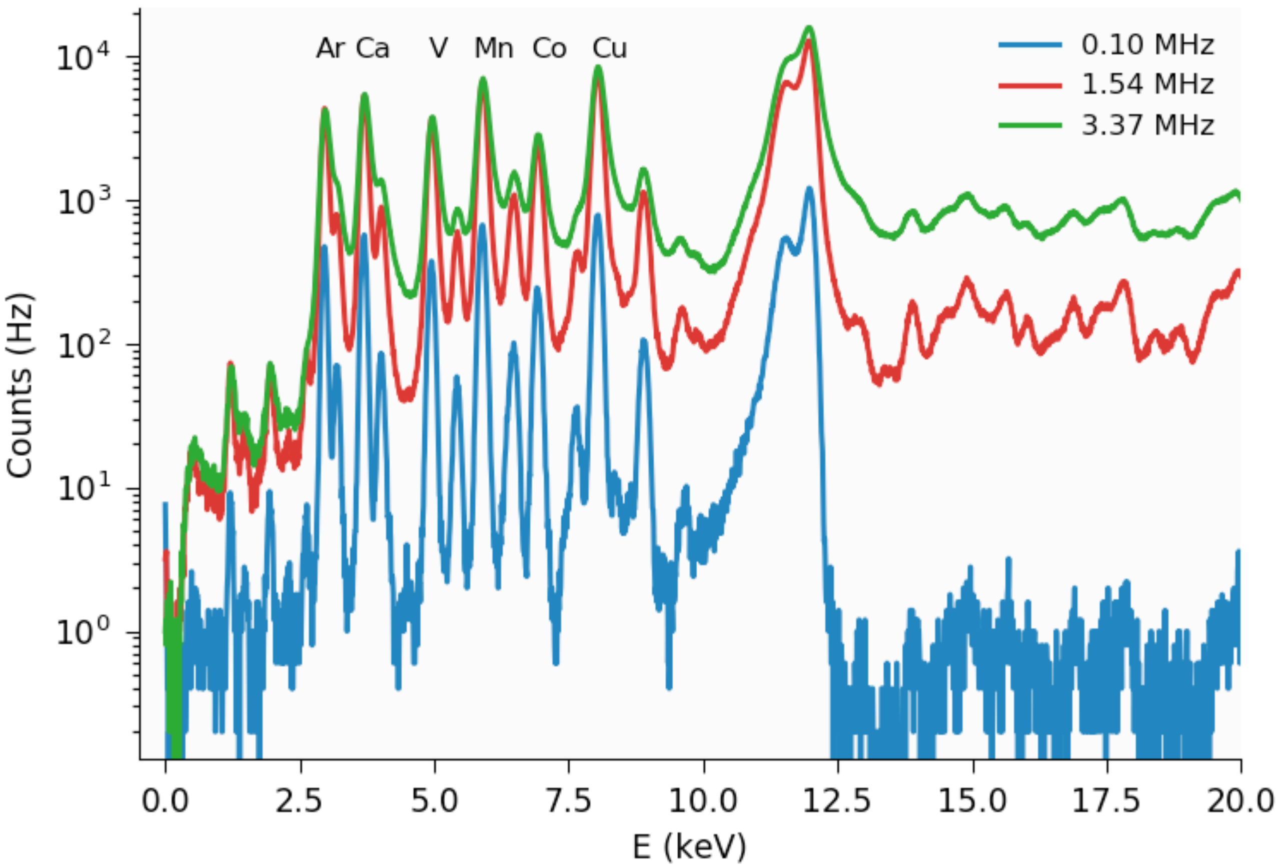
- Total maximum output count rate: >15 Mcps
- Guaranteed resolution: <135 eV FWHM (typ. below 125 eV)
- Energy range: 1 to 30 keV
- Collimated active area: 7 x 80 mm²
- Detector thickness: 0.5 mm

XGLab CUBE

Xspress3+SXD7: Example Spectra - Thin Film SRM1832

SRM 1832 is a thin-film standard sample with certified and ~equal concentrations of Ca, V, Mn, Co, and Cu: 10 to 200 ng / mm^2

Beamline : APS 13 ID-E slits open to allow maximum flux ~10^{13} Hz
X-ray Energy: 12 keV, Si (111). Collection Time: 5 seconds

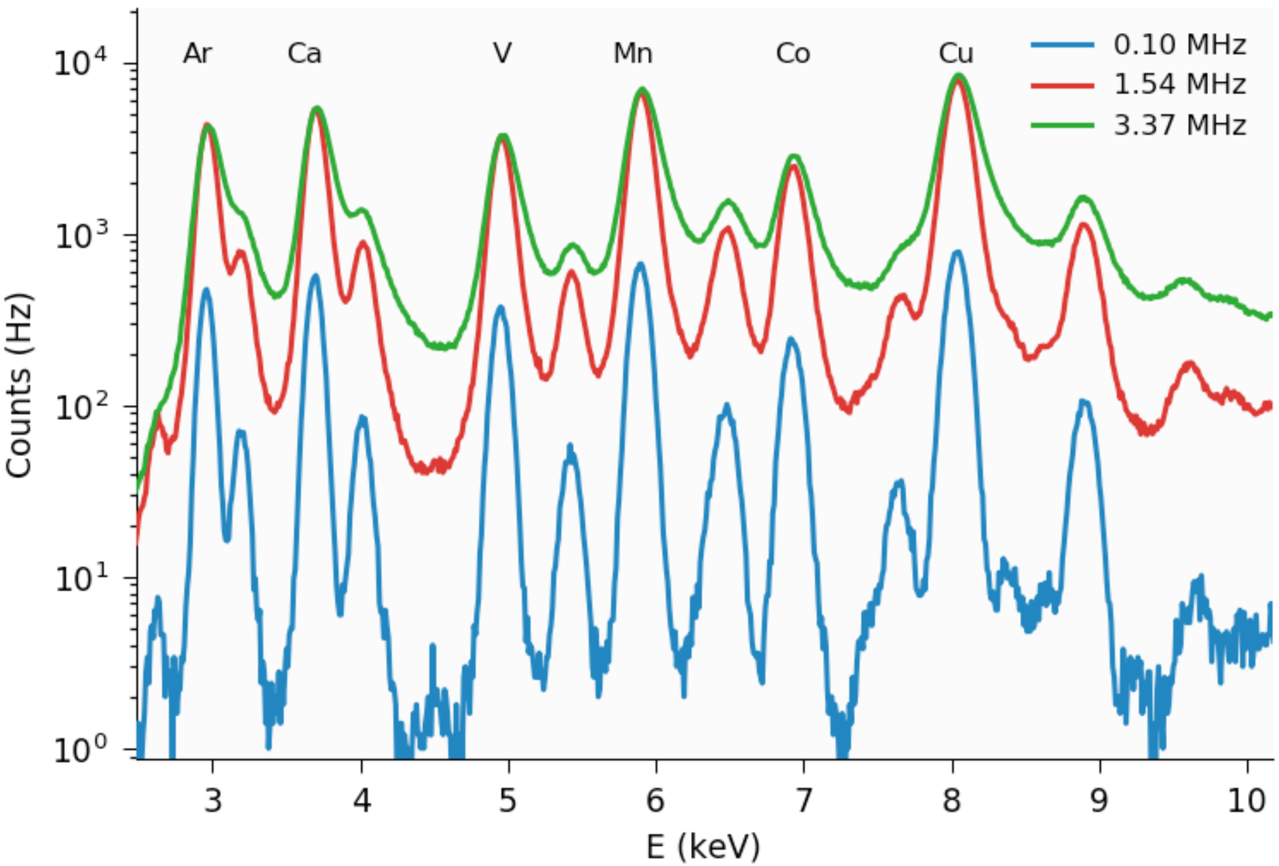


Data from 1 MCA Channel

Xspress3+SXD7: Example Spectra - Thin Film SRM1832

SRM 1832 is a thin-film standard sample with certified and ~equal concentrations of Ca, V, Mn, Co, and Cu: 10 to 200 ng / mm²

Beamline : APS 13 ID-E slits open to allow maximum flux ~10^{13} Hz
X-ray Energy: 12 keV, Si (111). Collection Time: 5 seconds



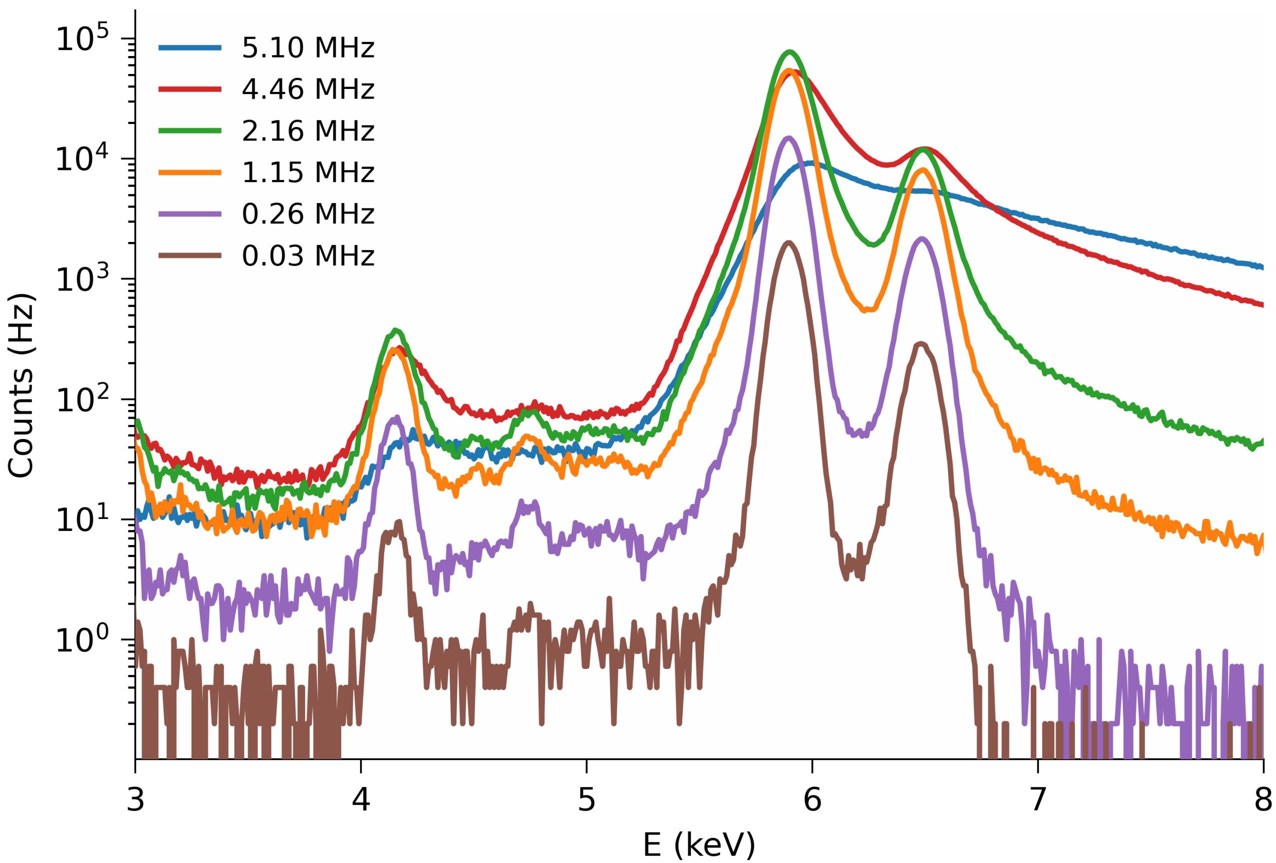
Analyzable spectra above 1.5 MHz per channel.

Data from 1 MCA Channel

Xspress3+SXD7: Energy Resolution at Mn K_α vs Count Rate

Using a Mn "foil" sample to measure Mn K_α peak position and resolution well past saturation

Beamline : APS 13 ID-E, adjusting slits to set flux ~10^{10} to ~10^{12} Hz
X-ray Energy: 12 keV, Si (111). Collection Time: 5 seconds



Analyzable spectra to about 2 MHz per channel.

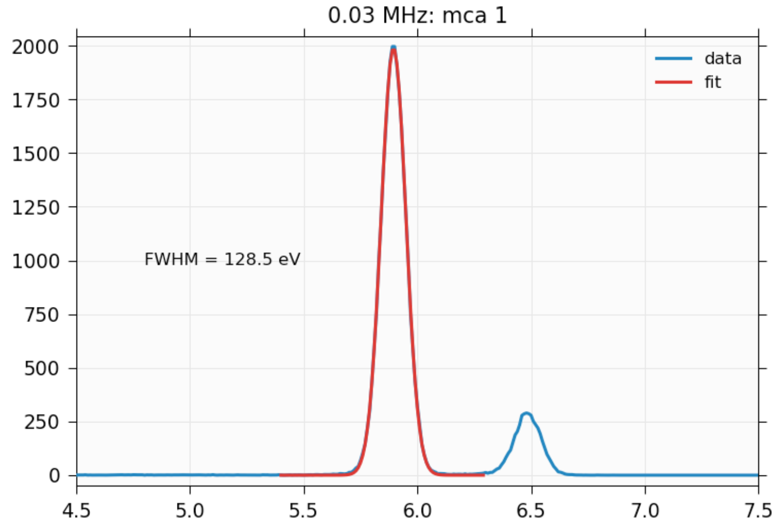
At 2 to 4 MHz, spectrum is saturated but usable.

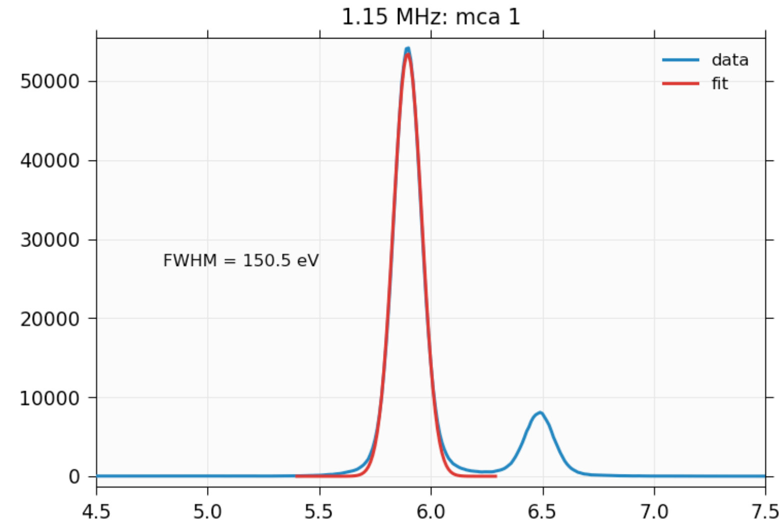
Data from 1 MCA Channel

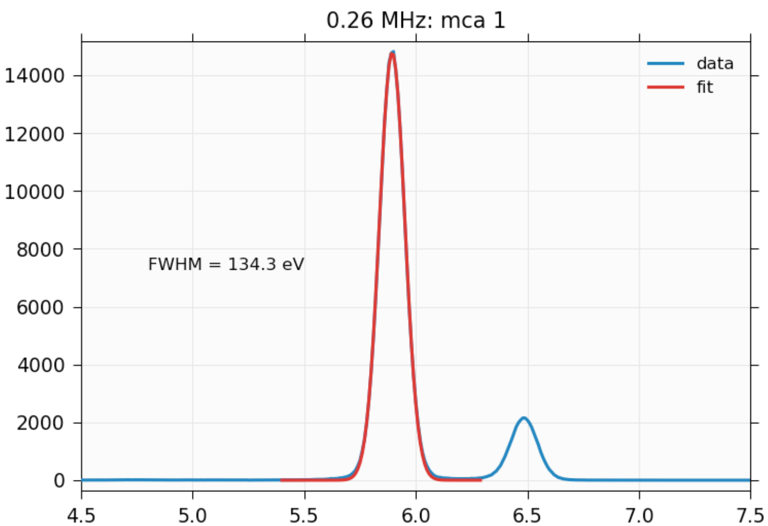
Xspress3+SXD7: Energy Resolution at Mn K_{α} vs Count Rate

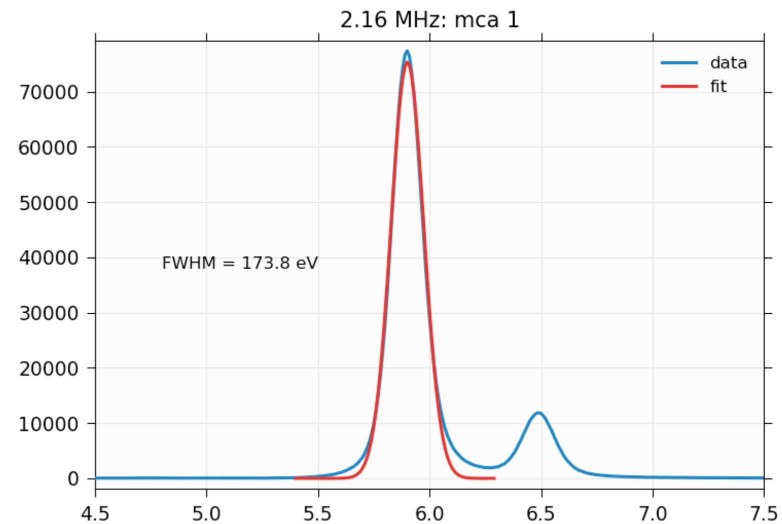
Measuring FWHM for representative spectra from Mn foil:

Data from 1 MCA Channel



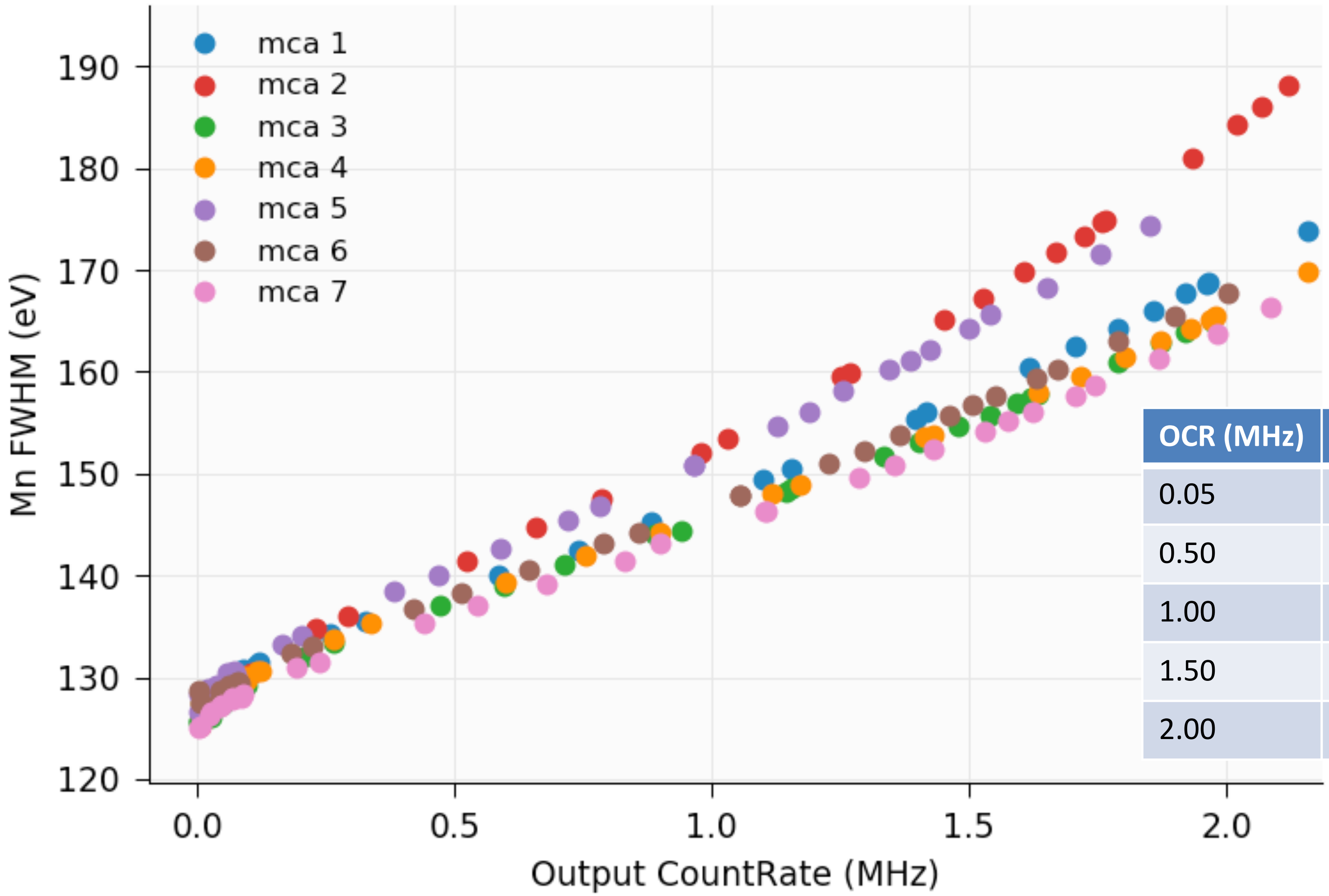






Xspress3+SXD7: Energy Resolution at Mn K_α vs Count Rate

Mn K_α FWHM vs Output Count Rate (OCR) up to 2MHz:

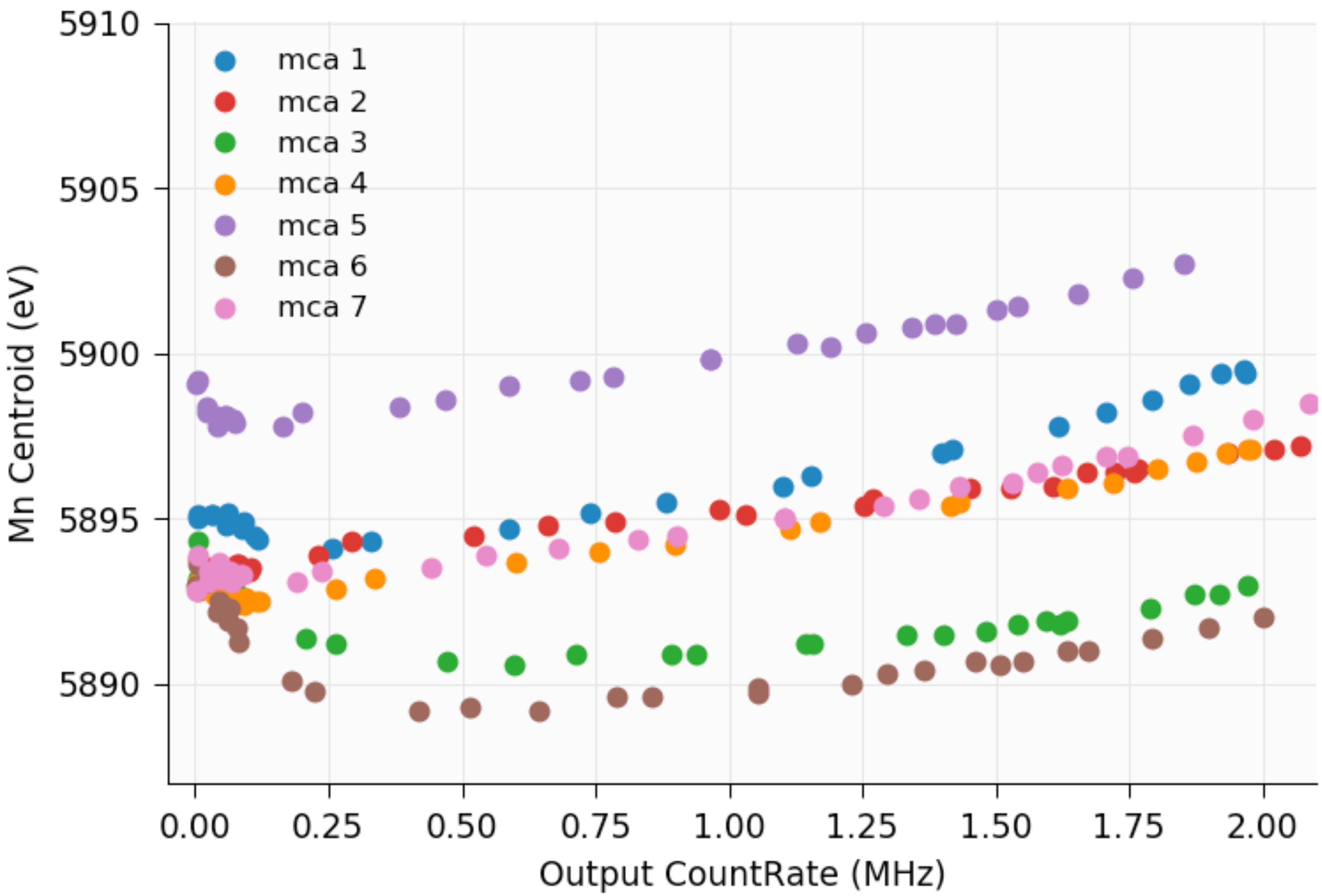


OCR (MHz)	Max FWHM (eV)
0.05	128
0.50	141
1.00	155
1.50	168
2.00	189

Xspress3+SXD7: Energy Position at Mn K_α vs Count Rate

Mn K_α Peak Positions vs Output Count rate up to 2MHz

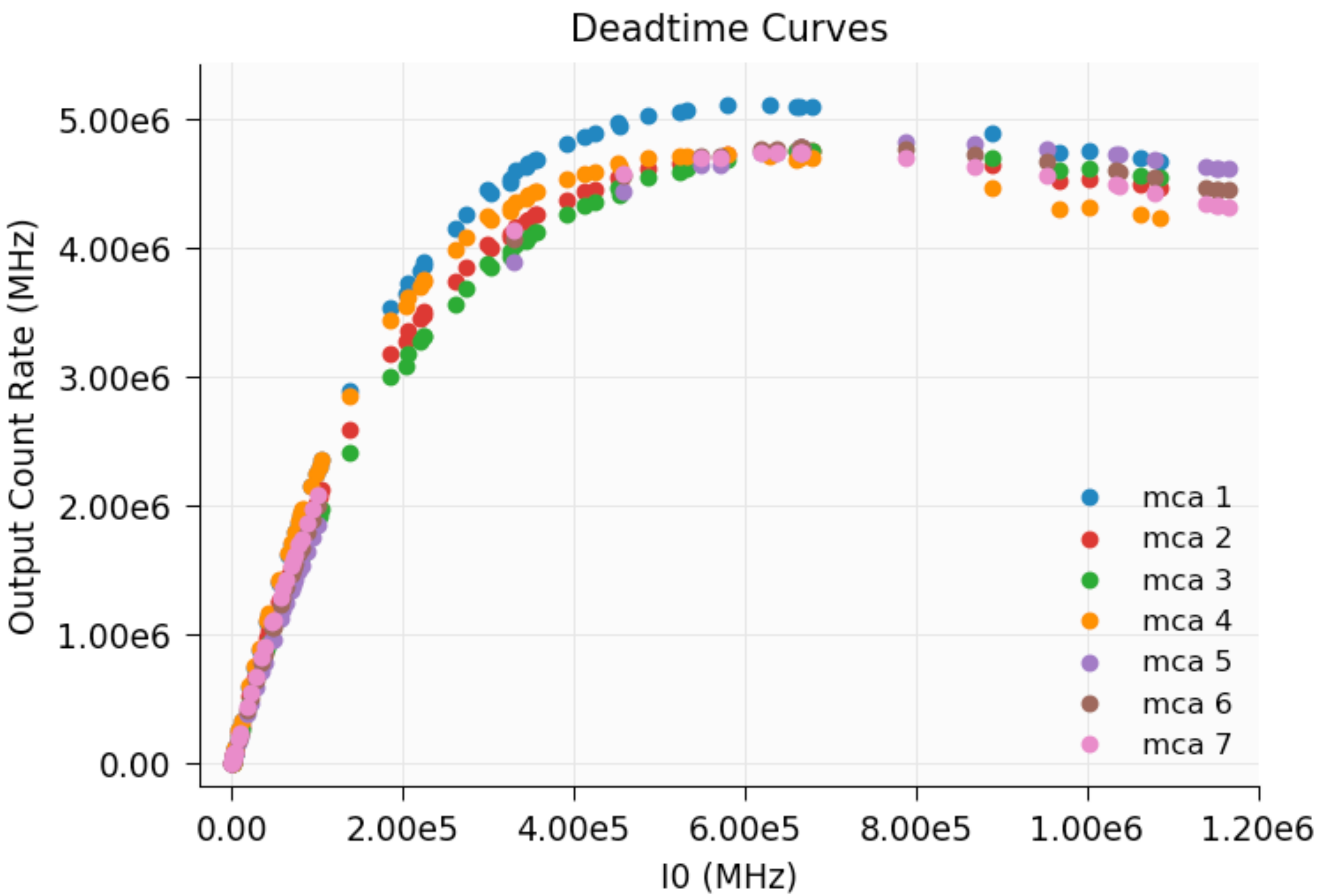
centroids drift by < 5 eV up to 2.0 MHz.   Energy bins are 10 eV, FWHM > 125 eV



Xspress3+SXD7: Dead Time Curves

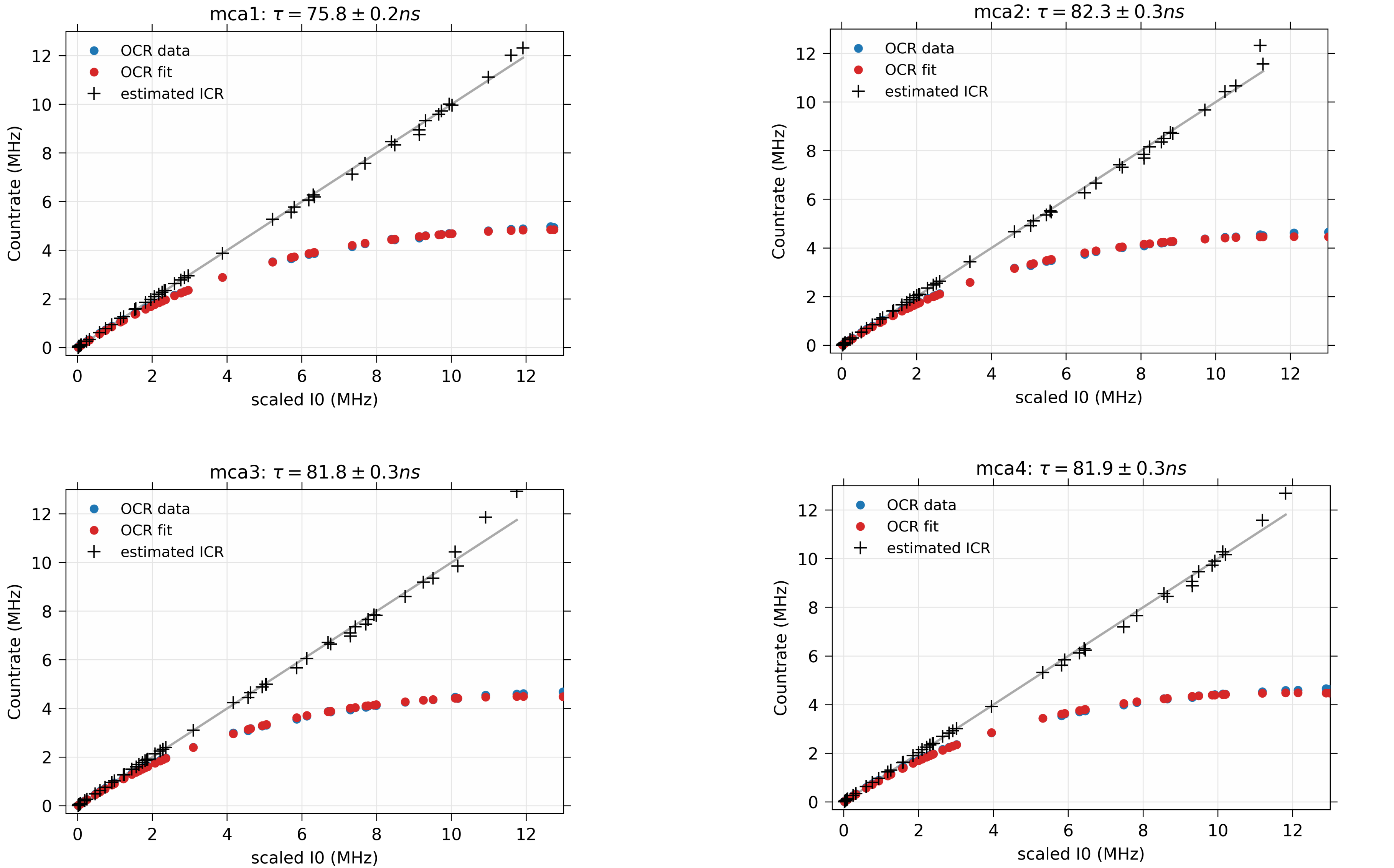
Output Count Rate vs Ion Chamber Flux well past detector saturation

Maximum OCR > 4.5 MHz, comparable to other detectors using CMOS / Cube Preamp



Xspress3+SXD7: Dead Time Curves

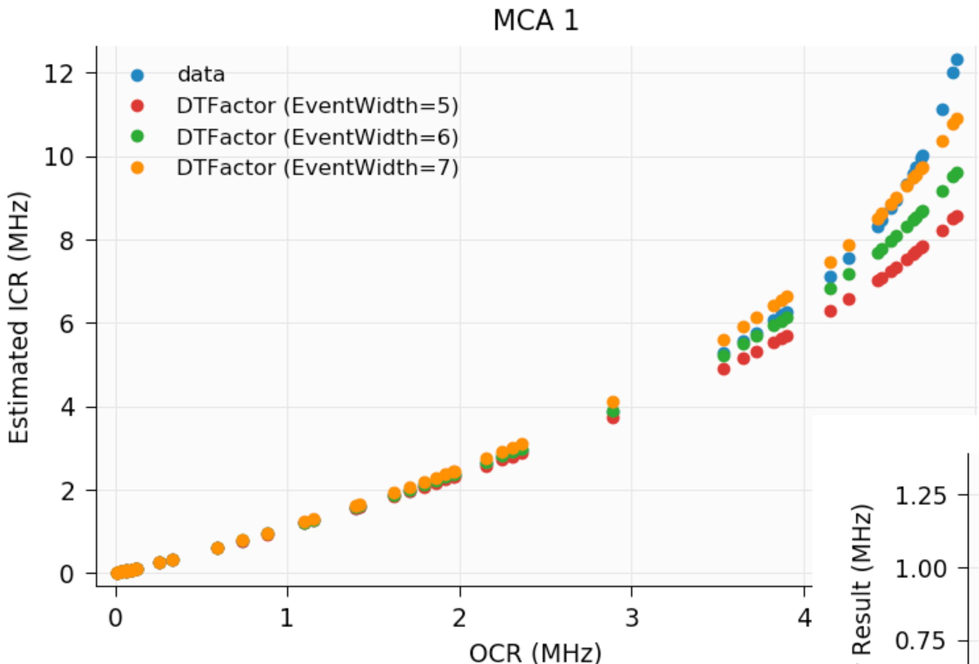
using OCR = ICR exp(-ICR τ), we can fit this data to estimate the deadtime τ. τ ~= 80ns



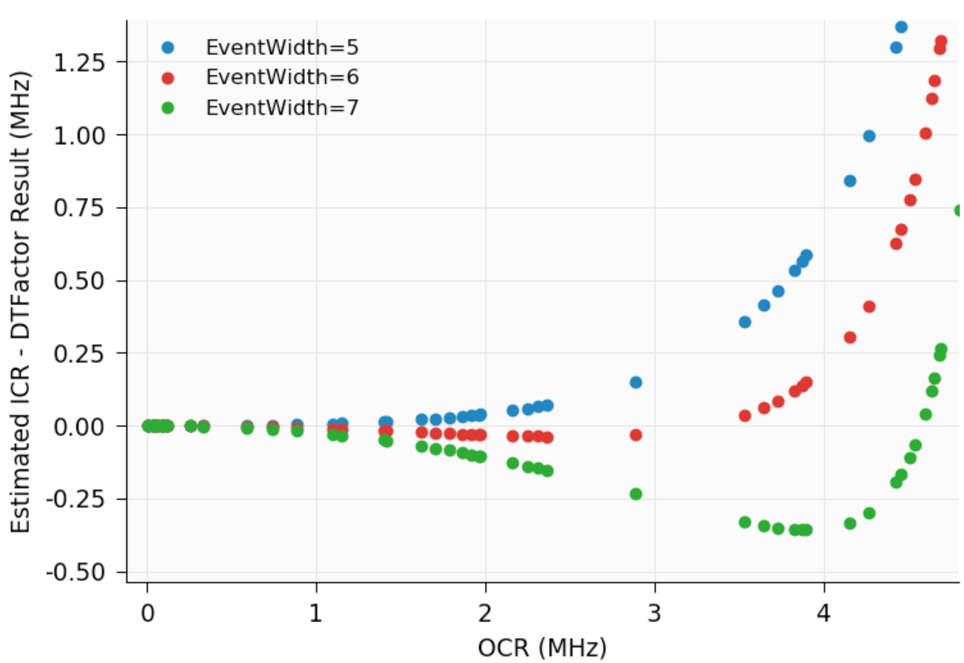
Xspress3+SXD7: Xspress3 Dead Time and EventWidth

Using

DTFactor = ClockTicks / (ClockTicks – (AllEvents*EventWidth + ResetTicks)



or, plotting the difference:



EventWidth = 6 (75 ns) should give a good deadtime correction to ~3 MHz

τ was fitted to be ~80 ns.

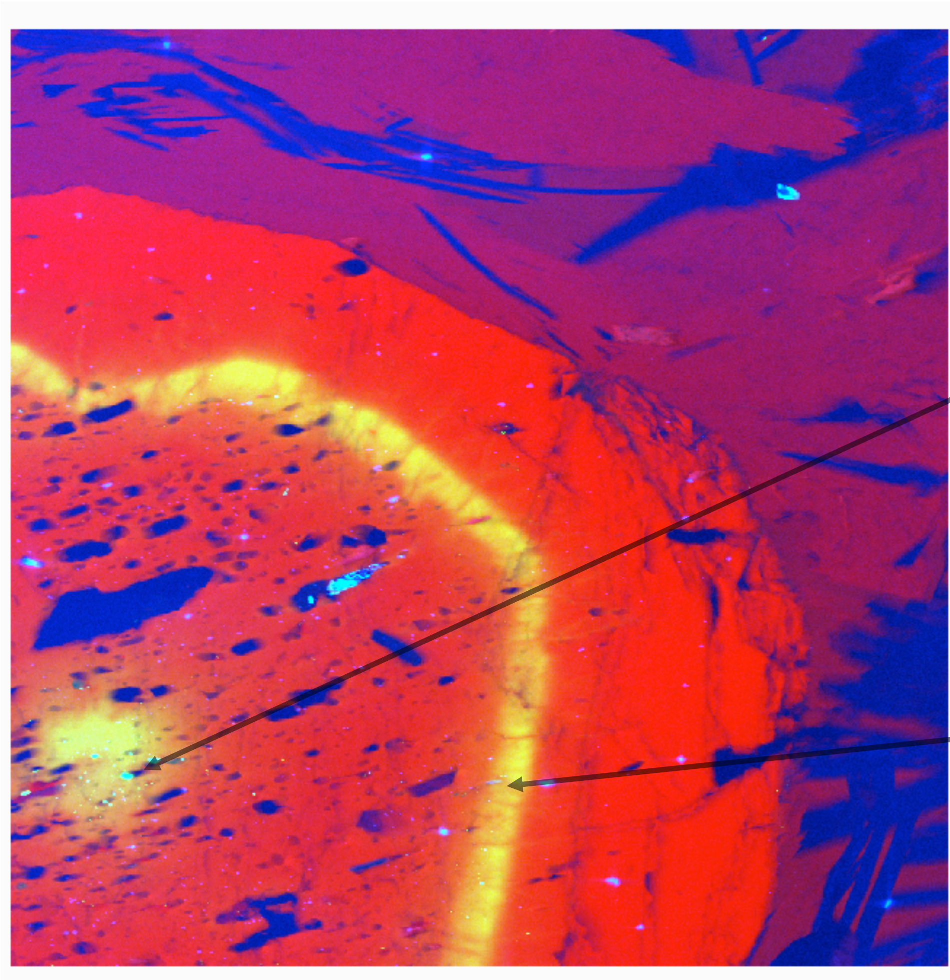
Similar results for the other detectors.

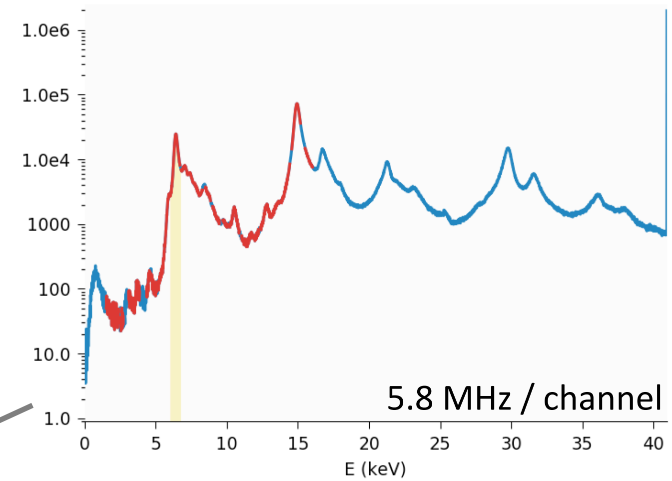
EventWidth = 6 or 7 for all channels.

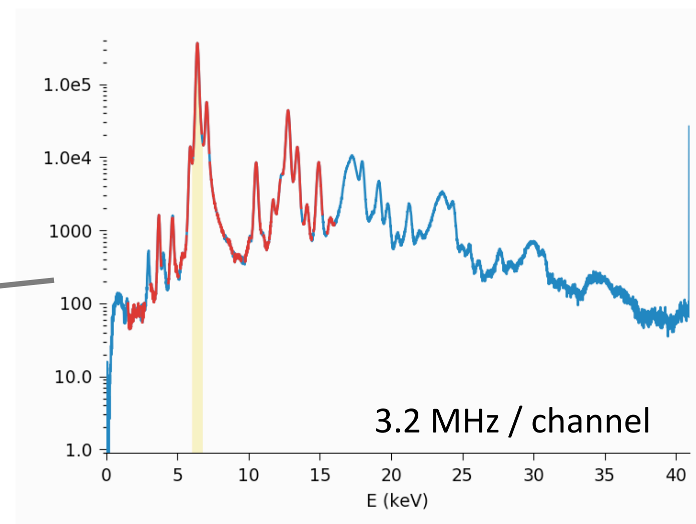
Xspress3+SXD7: XRF Mapping

An XRF Map (18keV) of a thin section of a garnet with random zircons (very high scattering) and banding in Y

1 x 1 mm area, 2 x 2 μm pixels, 20 ms per pixel (~90 min acquisition)







Fe / Ca / Y

Data Quality is very good to ~3MHz, no saturation artifacts up to 5.8 MHz

Data collection with Xspress3 Electronics

Mapping mode: Sample Stage motor controller triggers detector with TTL pulse (1 to 30 microseconds). For Xspress3, TriggerMode="TTL Veto Only"

- HDF5 Plugin streams the full data (Ndet X Nenergies) plus SCA values per pixel, with light compression.
- Works to about 1 kHz. At faster rates, frames start to get dropped.

ROI/QXAFS mode: Motor controller from monochromator triggers detector with TTL pulse, same as for mapping mode.

- ROIStats and SCA TimeSeries are used to produce a few 1D arrays per detector element: (1 or 2 ROIs, Outputcounts, DTFactor).
- Data are read from waverform PVs during/after scan for visualization.

Note: max count rate for 1 frame = 53.6 sec (2^{32} * 12.5e-9). Use multiple frames for longer acquisitions.

on to Epics display screens and data collection demo…

Extra Slides: What should we expect for FWHM – Fano effect

The peak width for pulse-counting detectors starts with assuming that the X-ray energy gets converted into countable electrons.

But the Poisson noise in the number of electrons over-estimates the observed noise – you are converting energy from one form to another, not generating random countable events.

Peak width σ is given by: FWHM = σ sqrt(8 log(2))

$$\sigma = \text{sqrt}\,(\,E * E_{e\text{-}h} * \text{FanoFactor} + \text{Noise}^2\,)$$

Where $E_{e\text{-}h}$ is the energy to create e-h pair. For Si,

$E_{e\text{-}h}$ = 3.6 eV and FanoFactor ~ 0.115

For Mn K_α (E = 5900 eV),

FWHM ~= 2.35 sqrt(5900 * 3.6 * 0.115 + Noise^2)

With Noise = 0 eV, FWHM = 117 eV
With Noise = 20 eV FWHM = 126 eV
With Noise = 30 eV FWHM = 137 eV

SXD7 Calibration with Xspress3 and Fe 55 Check Source

Calibrating with Mn K_α from Fe55 and Xspress3 auto-calibration app:

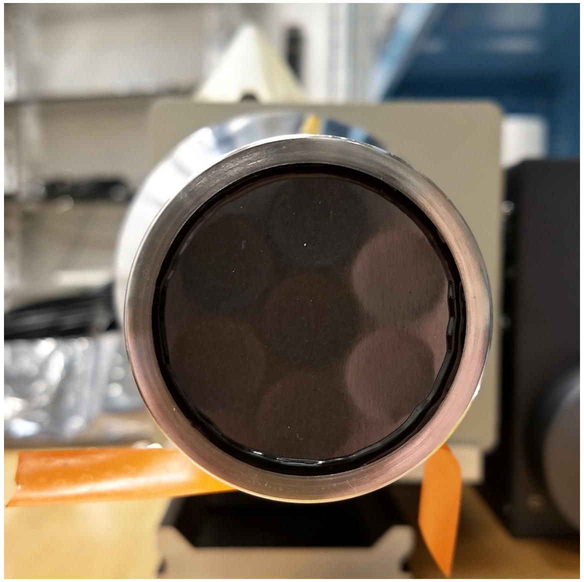
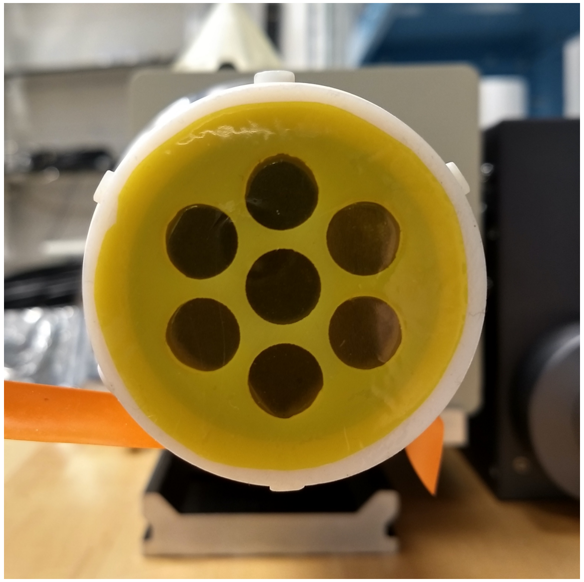
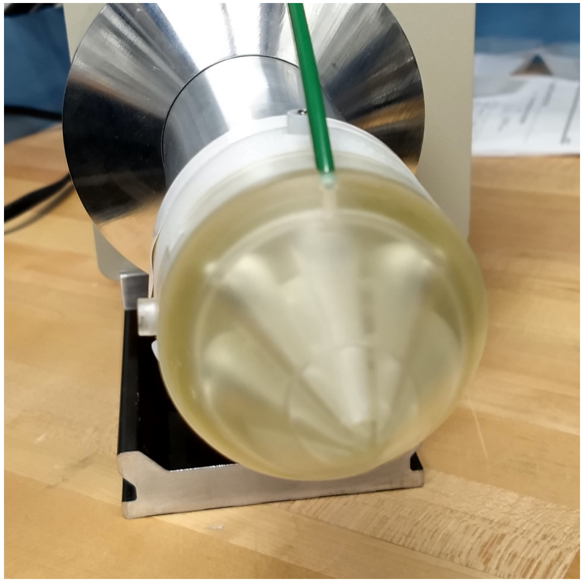
Mn K_α count rates ~5 to 10 kHz.
Each calibration procedure took about 20 minutes.

Channel	Xspress3 Centroid (eV)	Xspress3 FWHM (eV)	Mirion 2μs* FWHM (eV)	Mirion 8μs* FWHM (eV)
1	5892.6	124.9	124.4	122.7
2	5891.4	126.4	124.4	122.7
3	5891.7	123.2	124.9	123.1
4	5893.0	124.7	125.0	123.2
5	5894.2	126.2	125.0	123.4
6	5892.2	125.9	125.8	125.2
7	5892.7	125.4	124.4	122.9

*values measured by Mirion from their factory acceptance test report

SXD7: Collimator / Snout

We have a cover and collimator to restrict the field of view of each detector element to ~1 mm, and with an optimal working distance to ~60 mm

From a Similar collimator for ME-4, this will reduce background signals and window damage.

Tests presented here were done without this detector collimator

Solid Angle and Working Distance:

Detector	Snout diameter	# sensors	Sensor size	Solid Angle
SXD-7	50 mm	7	80 mm^2	@ 60mm WD: 0.012 sr
ME-4	38 mm	4	50 mm^2	@ 50mm WD: 0.006 sr

SXD7 Tests: setup

Cryo-Pumping and Cool-down time

The detector runs at -80^{o} C, using Canberra's Cryo-Pulse 5 pump and controller.

The manual says the cool-down time is ~4 hours. At ~4.5 hours it was at -75^{o} C and got to -80^{o} C. While cooling, the detector gave off a lot of heat, but then stabilized with very power use and a fan comparable to Hitachi ME-4.

The controller displays temperatures and power. These data can be sent over RS-232 to a Windows machine that can log these values. Yet to be tried: reading these values over serial port to Epics PVs