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Instruments that advance the art

The DGF Series of Multi-Channel Digital Spectrometers

XIA's DGF series of multi-channel spectrometers currently includes four products:

- the 4-channel DGF Pixie-4,
- the 4-channel DGF Pixie-500,
- the 4-channel DGF Pixie-500 Express, and
- the 16-channel DGF Pixie-16.

Continuing the design principles of XIA's DGF-4C CAMAC modules, all four spectrometers feature fast digitization of input signals from virtually any radiation detector, all-digital triggering, filtering and pile-up inspection, and an on-board DSP for pulse height reconstruction, pulse shape analysis and MCA histogramming. Modules can be combined into large groups with distributed timing and trigger signals for coincidence spectroscopy.

This document gives an overview of the four spectrometers, comparing their features and presenting typical performances in standard applications.

DGF Pixie-4

The DGF Pixie-4 is a 4-channel spectrometer for high precision applications. It has a very low noise analog input stage and features 14bit, 75 MHz ADCs. A 16bit fixed point DSP processes events at 75 MHz. It is a 3U PXI module; trigger distribution and run synchronization are implemented via the PXI backplane. Compatible with commercial CompactPCI/PXI computers, processors and interface cards, its small form factor allows robust and very compact data acquisition systems.

DGF Pixie-16

The DGF Pixie-16 is a 16-channel spectrometer intended for specific applications with large numbers of identical channels, such as highly segmented HPGe detectors. It features a low per-channel cost, a simplified analog input stage, and a large number of configurable trigger and coincidence signals distributed over an extension of the PXI backplane. Its 12-14bit ADCs digitize input signals at 100-250 MHz, and a 32bit floating point SHARC DSP processor runs at 100 MHz. A custom built 6U PXI crate is required for operation of the module.

DGF Pixie-500

The DGF Pixie-500 is a 4-channel digital spectrometer for fast detectors. It digitizes incoming signals with 12 bit, 500 MHz ADCs, and processes events in a 16bit fixed point DSP operating at 75 MHz. The Pixie-500 achieves very good timing resolutions and more than adequate energy resolution for good scintillators such as $LaBr_3$. It is a 3U PXI module; trigger synchronization and run synchronization are equivalent to the Pixie-4

DGF Pixie-500 Express

The DGF Pixie-500 Express (Pixie-500e) is a high speed 4-channel spectrometer based on the CompactPCI/PXI Express (PXIe) standard. The third generation of XIA's digital spectrometers, this spectrometer has ~8 times faster data I/O with large buffer memory to the host PC, a low noise analog input stage, and shares triggers with other modules via the PXIe backplane. It features a 14bit, 500 MHz ADC, and a 32bit floating point SHARC DSP running at 300 MHz.

Features

Analog input stage

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
Detector	Directly compatible with HPGe and Scintillator detectors with exponential decaying signals (e.g. RC-type preamp or PMT)			
Spectrometer input	50Ω or 8.5kΩ termination 1:8.8, 1:1 attenuation or input disable	50Ω or 2kΩ termination 1:8, 1:1 attenuation	50Ω or 5kΩ termination 1:7, 1:1 attenuation and input disable	50Ω or 1kΩ termination input disable or switchable attenuation
Termination select	Jumpers	Switches	Jumpers	Software controlled relays
Gain	2 coarse gains (1/3). Digital gain adjustment for channel matching.	2 coarse gains (1/3). Digital gain adjustment for channel matching.	64 gain steps (1..10). Digital gain adjustment for channel matching	2 coarse gains (1/4). Digital gain adjustment for channel matching.
Offset	+/- 2.0V DC, adjustable for each channel	+/- 2.0V DC, adjustable for each channel	+/- 2.5V DC, adjustable for each channel	+/- 1.5V DC, adjustable for each channel

Memory

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
MCA	32K bins per channel 2^{32} counts per bin	32K bins per channel, 384K bins for custom spectra (2D, sum) 2^{32} counts per bin	32K bins per channel 2^{32} counts per bin	32K bins per channel 2^{32} counts per bin
List mode data	8K words (16bit) I/O buffer in DSP 128K words (32bit) in external memory	256MB SDRAM used as FIFO	8K words (16bit) I/O buffer in DSP 128K words (32bit) in external memory	64K words (32bit) I/O buffer in DSP 256K words (16bit) in external FIFO memory

Digital processing

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
Digitization	12bit, 500 MHz ADC	14bit, 500 MHz ADC (and custom options)	14bit, 75 MHz ADC	14bit, 100 MHz ADC 12bit, 250 MHz ADC (and custom options)
Triggering, filtering, pile-up inspection	In Xilinx Virtex-4 FPGA at 125 MHz	In Xilinx Virtex-4 FPGA at 125 MHz	In Xilinx Spartan II FPGA at 75 MHz	In Xilinx Spartan 6 FPGA at >=100 MHz
Waveform acquisition	up to 8K ADC samples per channel at 500 MHz (16µs)	up to 4K ADC samples per channel at 500 MHz (8µs) pulses buffered in front end (ZDT)	up to 1K ADC samples per channel at 75 MHz (13.6µs)	up to 4K ADC samples per channel at 100 or 250 MHz (16-40µs) pulses buffered in front end (ZDT)
Energy reconstruction and pulse shape analysis	In 16bit fixed point DSP at 75 MHz	In 32bit floating point SHARC DSP at 300 MHz	In 16bit fixed point DSP at 75 MHz	In 32bit floating point SHARC DSP at 100 MHz

Digital I/O

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
Data bus to host PC	PCI, 33MHz, 32 bit	PCI Express x4	PCI, 33MHz, 32 bit	PCI, 33MHz, 32 bit
I/O transfer rate	up to 109Mbytes/s sustained	up to 800Mbytes/s (hard drive limited)	up to 109Mbytes/s sustained	up to 109Mbytes/s sustained
Front panel	1 DSP output, 1 FPGA I/O for timing, trigger or veto signals	11 FPGA I/O for trigger, gate, or veto	1 DSP output, 1 FPGA I/O for timing, trigger or veto signals	>20 FPGA I/O for trigger, coincidence, timing or veto signals.
Backplane lines	Bussed, star, daisy-chained clock (3) Bussed trigger (2) Neighbor trigger (2) Run synchronization, Veto, Status, Module coincidence (4)	PXIe clock (2) Bussed trigger, Run synchronization, Veto, Status (6) PXIe high speed STAR trigger lines	Daisy-chained or star clock (2) Bussed trigger (2) Neighbor trigger (2) Run synchronization, Veto, Status, Module coincidence (4), Channel Gate (4)	Daisy-chained or star clock (2) Basic trigger, run synchronization Veto, spare (8) Bussed I/O (124) Neighbor I/O (74) Control (8)

System

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
Form Factor	3U CompactPCI/PXI	3U CompactPCI/PXI Express	3U CompactPCI/PXI	6U CompactPCI/PXI
Chassis	Any 3U PXI chassis. Up to 17 modules per chassis; multiple chassis can be linked with PCI bridges	Any 3U PXIe chassis. Up to 17 modules per chassis; multiple chassis can be linked with PCIe bridges	Any 3U PXI chassis. Up to 17 modules per chassis; multiple chassis can be linked with PCI bridges	6U PXI chassis with high power backplane. Up to 13 modules per chassis; multiple chassis can be linked with PCI bridges
Connection between chassis	Link PXI-PDM modules in slot 2 to distribute clocks and triggers		Link PXI-PDM modules in slot 2 to distribute clocks and triggers	Use Rear I/O modules for LVDS clock, trigger and data connections
Controller	CompactPCI/PXI embedded computer or PCI-cPCI bridge for remote control from PC	CompactPCI/PXIe embedded computer or PCIe-cPCIe bridge for remote control from PC	CompactPCI/PXI embedded computer or PCI-cPCI bridge for remote control from PC	CompactPCI/PXI embedded computer or PCI-cPCI bridge for remote control from PC

Software

	DGF Pixie-500	DGF Pixie-500e	DGF Pixie-4	DGF Pixie-16
Standard	FPGA and DSP code to calculate pulse heights, acquire wave-forms, accumulate MCA and CFD timing in DSP C driver library to run modules User interface based on Igor Pro graphics and analysis software	FPGA and DSP code to calculate pulse heights, acquire wave-forms, accumulate MCA C driver library to run modules User interface based on Igor Pro graphics and analysis software	FPGA and DSP code to calculate pulse heights, acquire wave-forms, accumulate MCA and CFD timing in DSP C driver library to run modules User interface based on Igor Pro graphics and analysis software	FPGA and DSP code to calculate pulse heights, acquire waveforms and accumulate MCA C driver library to run modules Visual Basic user interface as demo for C driver library
User customization	Add user routines to DSP code, Integrate C driver into existing user interface Add routines to Igor user interface			

Performance

Resolution

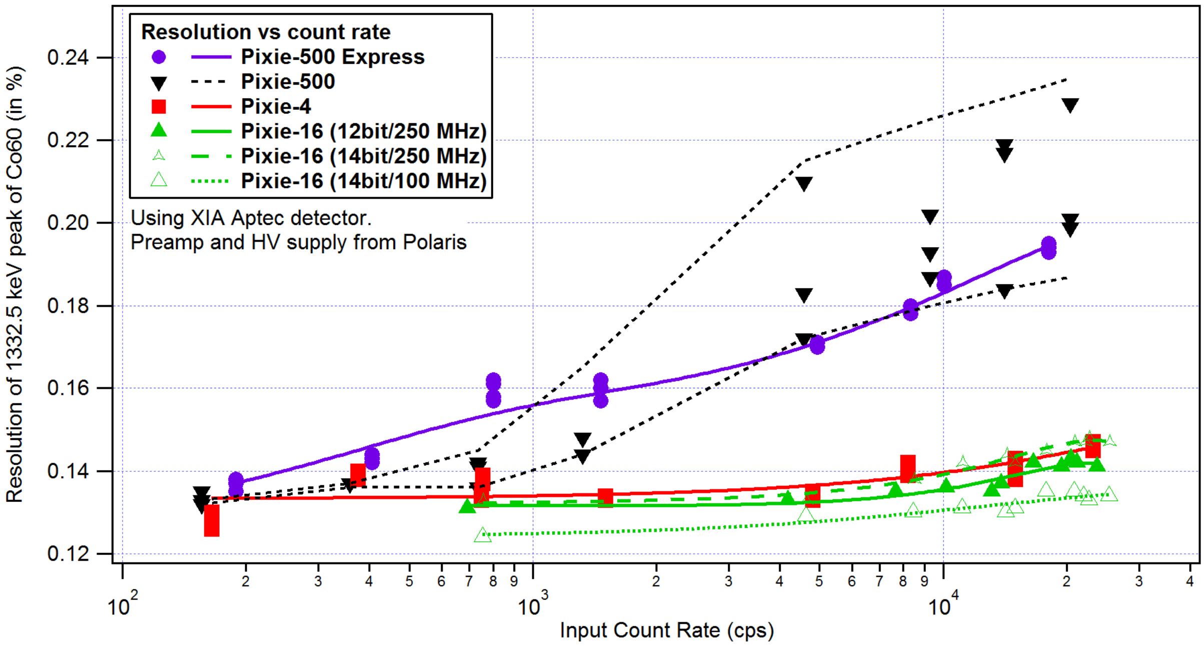

Fig.1: Resolution of the 1332.5 keV peak of ^{60}Co for Pixie-4, Pixie-16, Pixie-500, and Pixie-500e as a function of count rate. The lines are guides for the eye only. The measurements used XIA's Aptec detector, with preamplifier power and HV supply provided from external supplies. In most cases resolutions were measured with several channels for each rate, hence multiple data points. The scatter of data points for the Pixie-500 is a consequence of the relatively poor linearity of the ADC. The black dashed lines indicate a range of resolution that can be expected. These results are typical for the specific detector used and may differ in other systems.

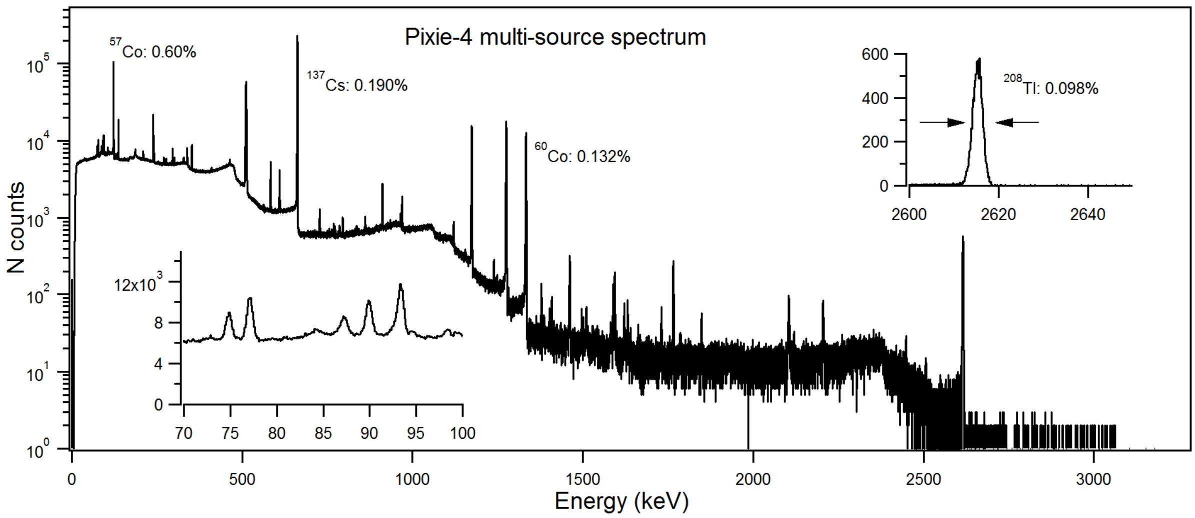

Fig. 2: Multi-source MCA spectrum for Pixie-4. The full dynamic range in this acquisition was about 3.6 MeV. Peak resolutions less than 0.1% FWHM can be achieved with a suitable detector, with no artifacts at low energy peaks.

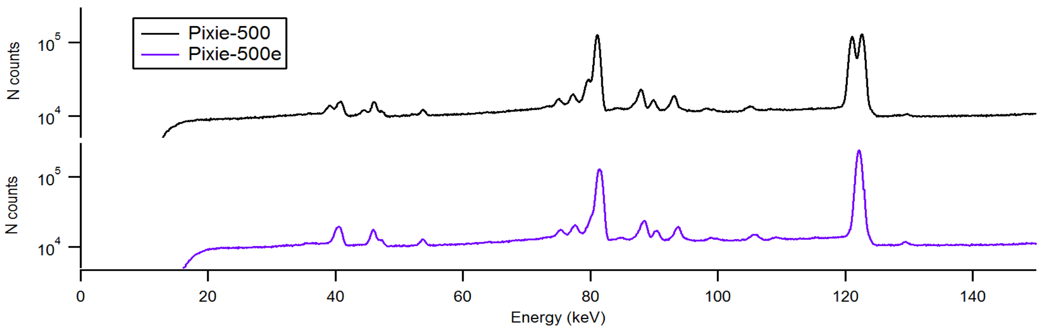

Fig.3: The ADC used on the Pixie-500 is designed for high speed, not necessarily high precision. The ADC on the Pixie-500e is a more modern device with better linearity. The resulting difference in performance can be seen in the low energy peaks of the MCA spectrum (signal from same detector, same time). When pulse heights become comparable to nonlinearities in the Pixie-500 ADC (often visible as small discontinuities in the ADC-out vs Voltage-in response), some peaks split into doublets. Thus we do not recommend the Pixie-500 for high precision detectors like HPGe detectors, though it is well suited for scintillators (and a cheaper alternative to Pixie-500 Express).

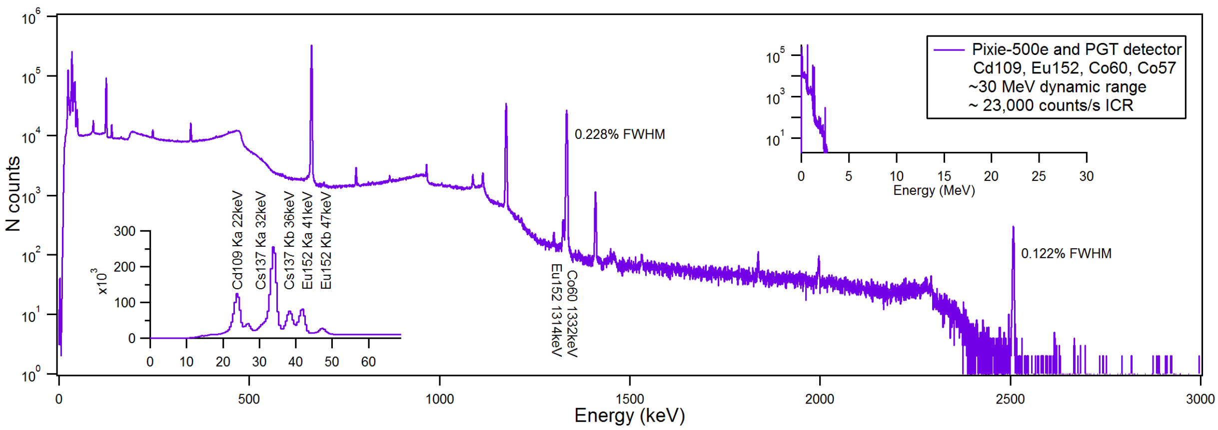

Fig.4: Even at fairly extreme conditions, ~30 MeV dynamic range and >20,000 counts/s, the Pixie-500e produces acceptable spectra. No artifacts due to nonlinearities are observed at low energy peaks, Kα and Kβ X-rays are well resolved, and resolutions are still ~0.12% at 2.5 MeV.

Throughput

Throughput was measured in two ways: a single channel of the spectrometer is connected to the signal source or all channels of the spectrometer are connected to the same signal source. Connecting a single channel gives the limit of non-coincident throughput, i.e. pulses arrive randomly at unrelated channels and are processed one at a time. Connecting all channels gives the limit of coincident throughput, i.e. 4 or 16 pulses being processed together. This is usually more efficient – it takes longer than processing a single pulse, but less than four or sixteen times as long.

In MCA only runs, with peaking times set long enough to get reasonable energy resolution, the maximum throughput is usually limited by the energy filter dead time. In list mode runs, the throughput is limited by the data rate, i.e. the speed with which the module can send data to the host PC because only a limited number of events can be buffered in on-board memory (depending on length of captured waveforms).

Shown below are the results with the general purpose software. For all of XIA's spectrometers, the DSP code can be optimized for very high throughput (with reduced pulse height precision).

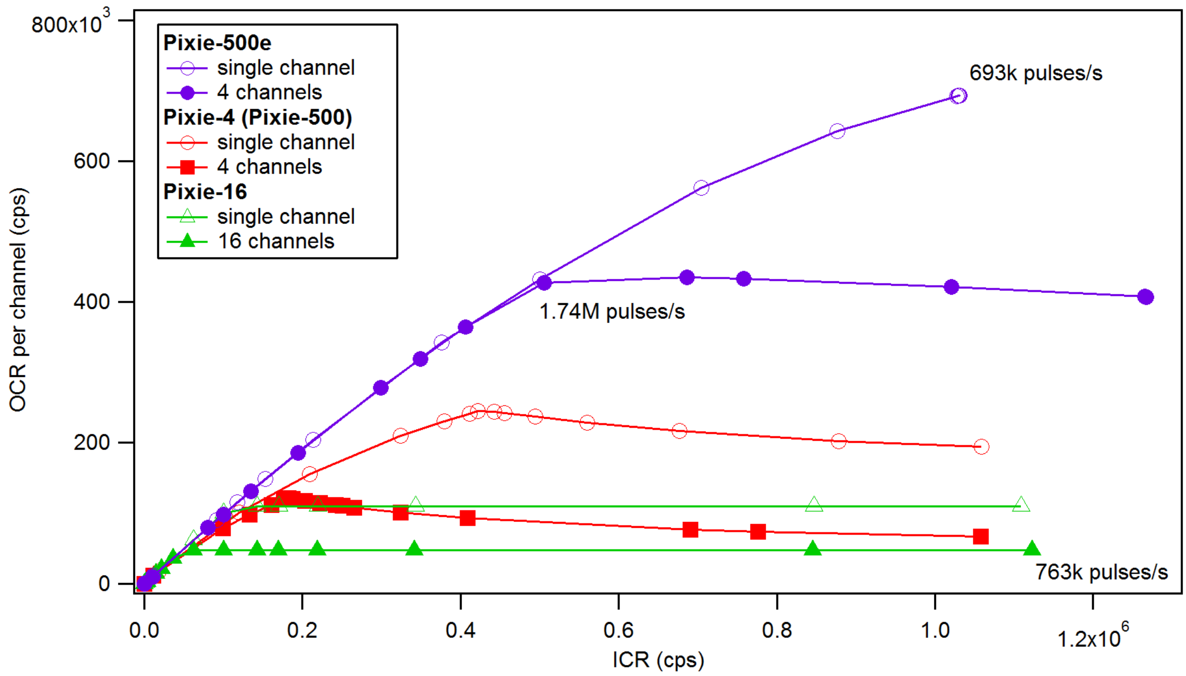

Fig. 5: Processed data rates (throughput of pulses *per channel*) for DGF Pixie modules. Measured in MCA mode with a random pulse generator with very short energy filter. Throughput as function of input count rate follows Poisson statistics until it reaches a plateau set by the processing limit (or decreases due to higher processing load).
The maximum throughput of pulses is
~245,000 pulses/s for a single channel and ~484,000 pulses/s for 4 channels with the Pixie-4,
~693,000 pulses/s for a single channel and ~1,740,000 pulses/s for 4 channels with the Pixie-500e,
~109,000 pulses/s for a single channel and ~763,000 pulses/s for 16 channels with the Pixie-16.
The maximum throughput for the Pixie-500 is similar to the Pixie-4 ; the same DSP processes events at the same speed.

Timing

Currently timing information is provided in several ways:

- At the time of triggering, each event is time stamped in every channel. This provides an event ID with 13.3 ns, 10 ns and 8 ns precision for the Pixie-4, Pixie-16, and Pixie-500(e) respectively. The ID has limited use for time resolution measurements because of the trigger walk at different pulse heights.
- In the Pixie-4 and Pixie-500, the DSP contains code to determine the trigger time at a constant fraction of the pulse amplitude. This time is calculated to a precision of 1/256 of the sampling interval, i.e. 51 ps for the Pixie-4 and 8 ps for the Pixie-500.

For most precise and comparable timing information, captured waveforms can be analyzed offline. The result depends strongly on two issues: 1) The method of how to find the timing reference for the pulse. Examples are simple threshold, constant fraction threshold, or template fits. 2) The signal source. A pulser split into 2 has much less jitter than 2 separate detector channels (e.g. Scintillator and PMT) with different noise and transit delays. Figures 6-8 show results for different setups and devices. The pulser results represent the limit set by the electronics, while the detector results represent typical performance in real experiments with detectors adding noise and jitter. Experimental conditions vary slightly for the different Pixie modules.

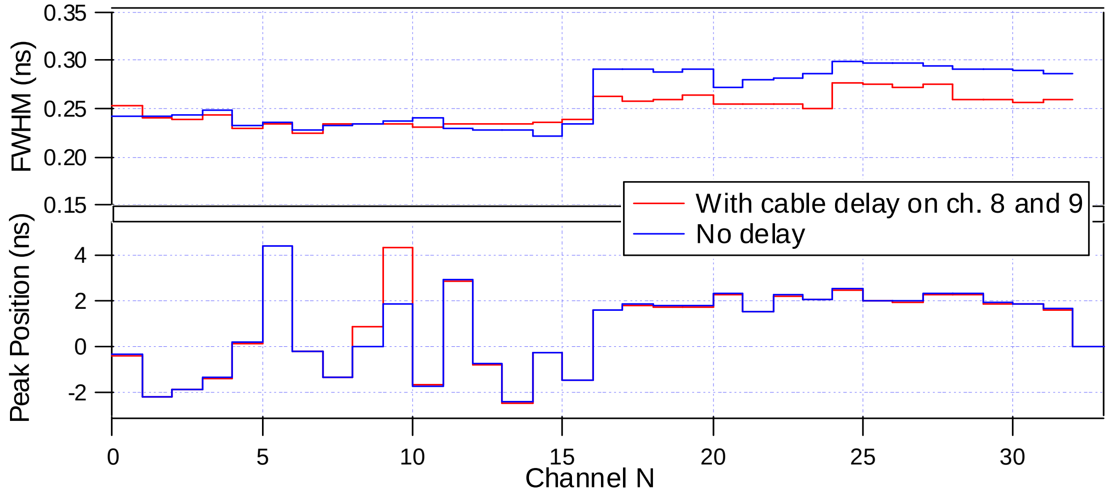

Fig. 6: Using two Pixie-16 modules with a common pulser signal fanned out to 1 "center contact" and 32 slave channels, the time of arrival was calculated with an offline CFD algorithm for the waveforms acquired by each channel. Calculating the time difference between center and slave channels for 700 acquired waveforms gives a distribution of time differences that were binned into histograms; the top graph shows the peak position and the bottom graph the FWHM of each distribution. When a cable delay is introduced for some channels, their peak position shifts, else peak positions and FWHM remains the same in repeated acquisitions.

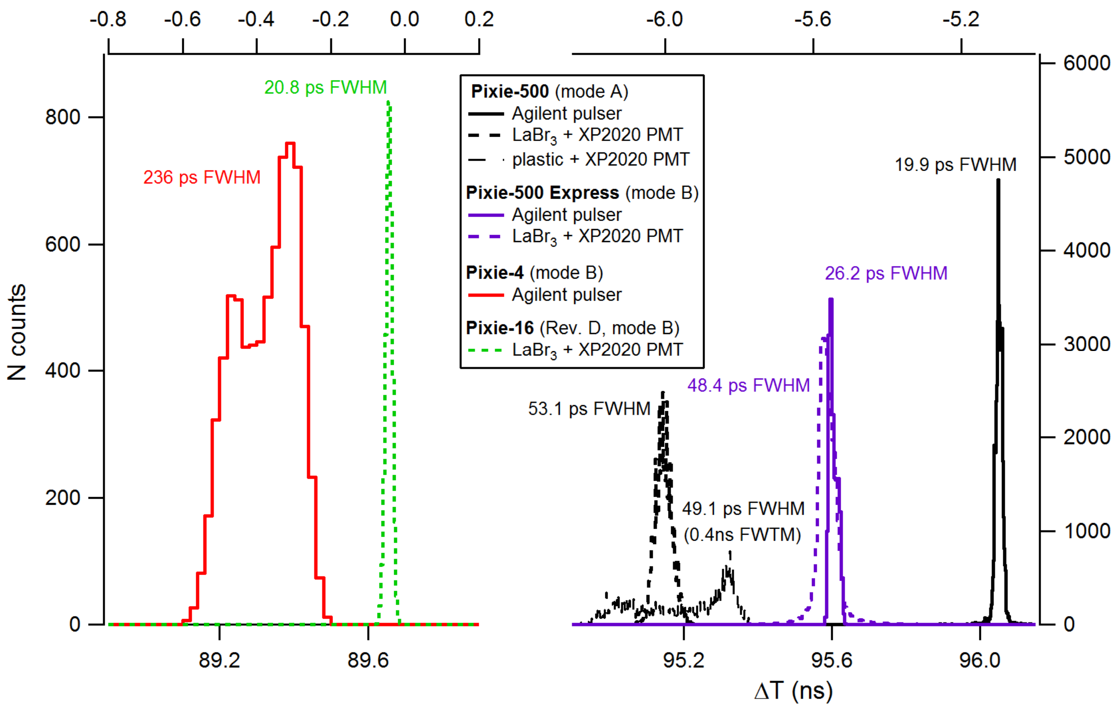

Fig. 7. Histograms of measured time difference ΔT between the two rising edges of a double pulse (mode A) using P500, and between pulses split between 2 channels (mode B) using Pixie-4, Pixie-16 and Pixie-500 Express.

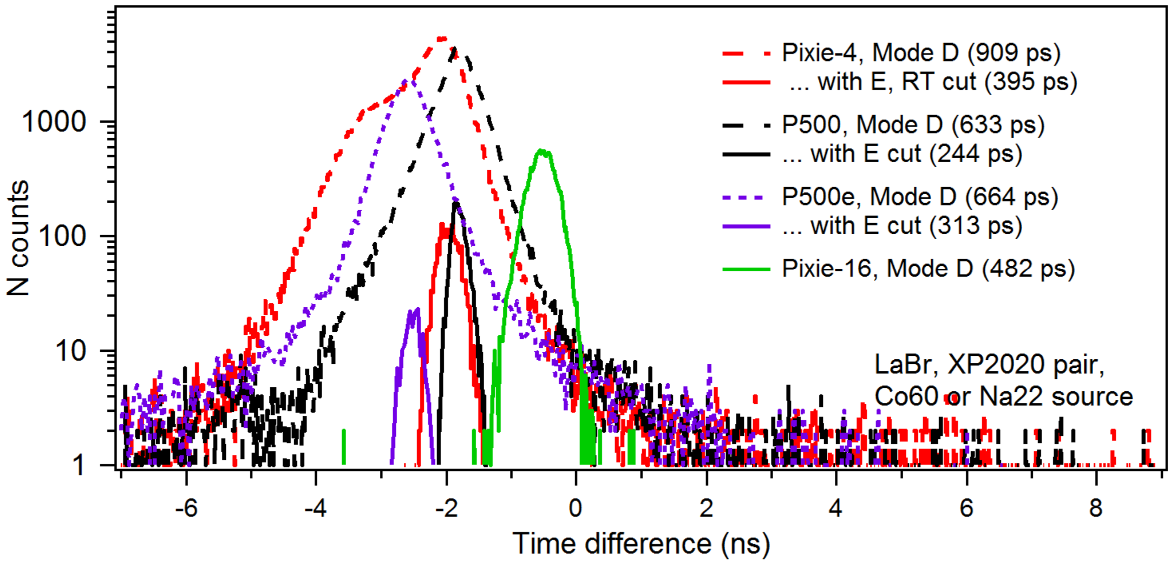

Fig. 8. Histograms of measured time difference ΔT between two detectors with a coincident source (Na-22 or Co-60) fed into 2 channels (mode D). For the co-60 measurements, an energy (and rise time cut) can be applied to limit the analysis to pulses with E>1MeV, which improves the timing resolution, but removes a significant number of events.

Linearity

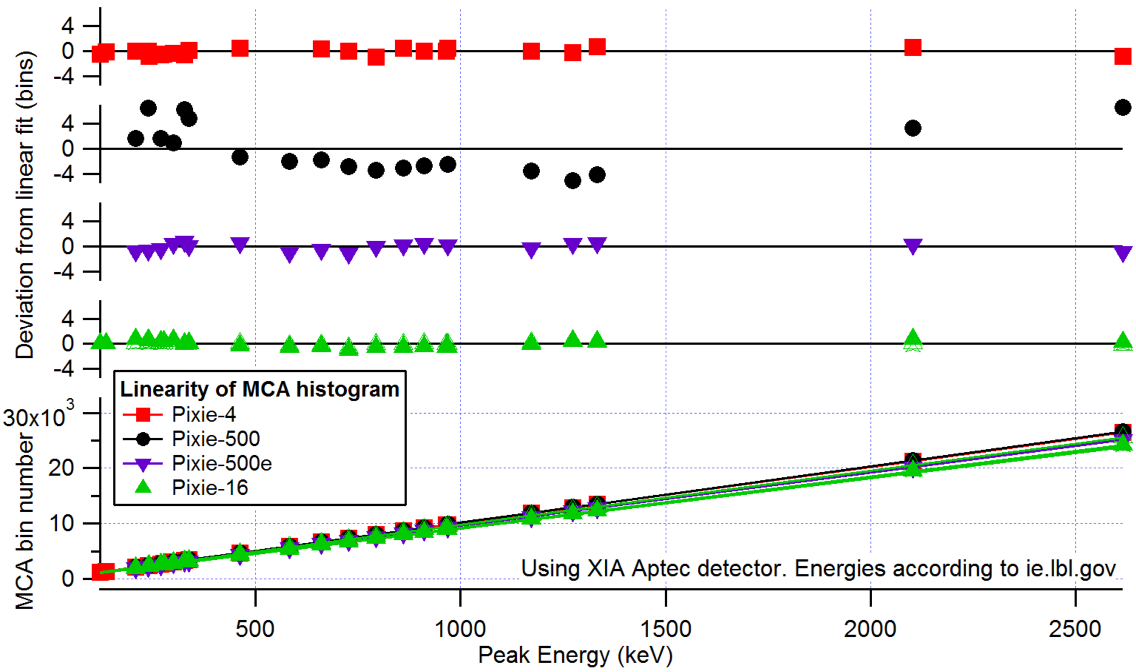

Fig. 7: Peak positions of multi-line spectra acquired with Pixie-4, Pixie-500, Pixie-500e and Pixie-16 as a function of nominal energy; as well as the deviation from a linear fit. Measured with XIA's Aptec detector with natural Th and Cs, Co and Na sources. The spectra were acquired for several hours at an input count rate of approximately 8kcps (Pixie-4, Pixie16) or ~1.2kcps (Pixie-500, Pixie-500 Express).

Electronic noise

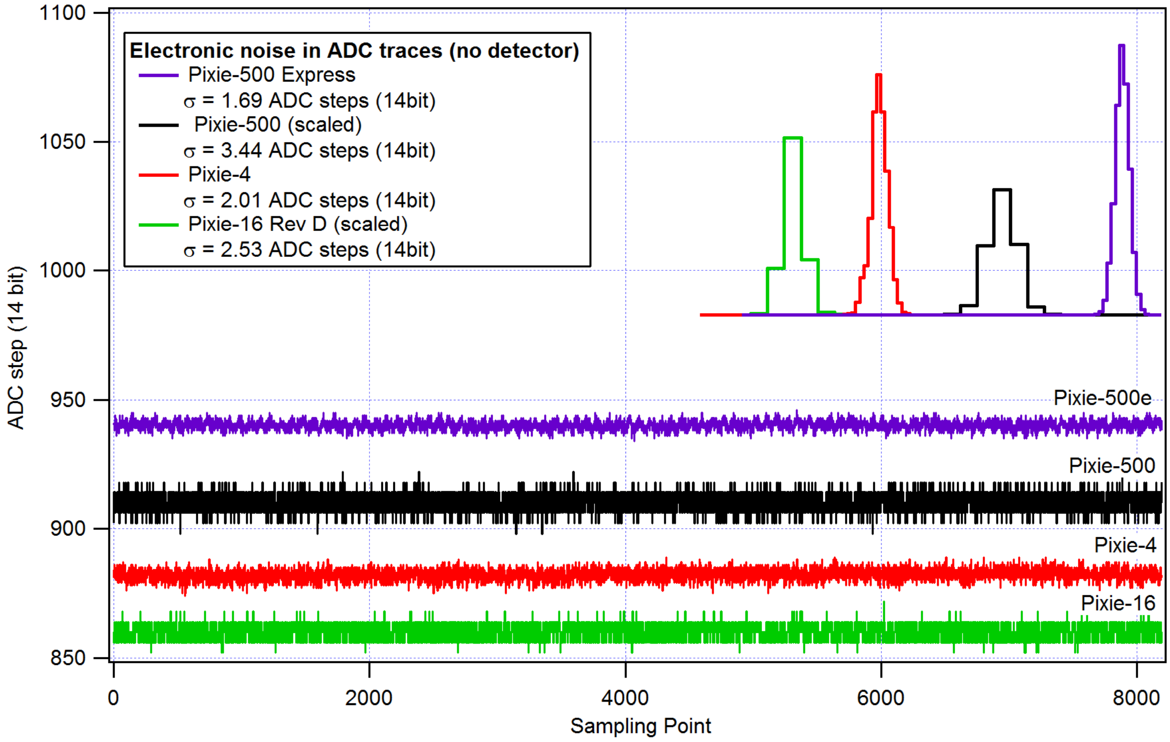

Fig.8: Untriggered traces of 8K subsequent ADC samples give an estimate of the electronic noise of the input stages of Pixie-4 , Pixie-500, Pixie-500e and Pixie-16. Inputs were left unconnected. The sampling interval is 53 ns for Pixie-4 and Pixie-500, 67 ns for Pixie-500e, and 75 ns for Pixie-16. The trace of the Pixie-500' and Pixie-16's 12bit ADCs are scaled to 14bit numbers for comparison. The inset shows a histogram of the values in each trace; the standard deviation of the average of trace values is given as a measure of the noise.

"Zero dead time" event capture

It generally requires a certain amount of time, in the order of a few microseconds, to process events. In the newer Pixie models, pipelining the event processing and buffering multiple events allows capturing even closely following events. The only separation requirement on the event capture is then the width of the energy filter – if two pulses follow more closely than the pulse integration time to average the pulse height, the result is incorrect, so both pulses are rejected – which however can be disabled by the user. The time difference between subsequent recorded pulses can then approach zero and recorded waveforms can even overlap, see Figures 9 and 10.

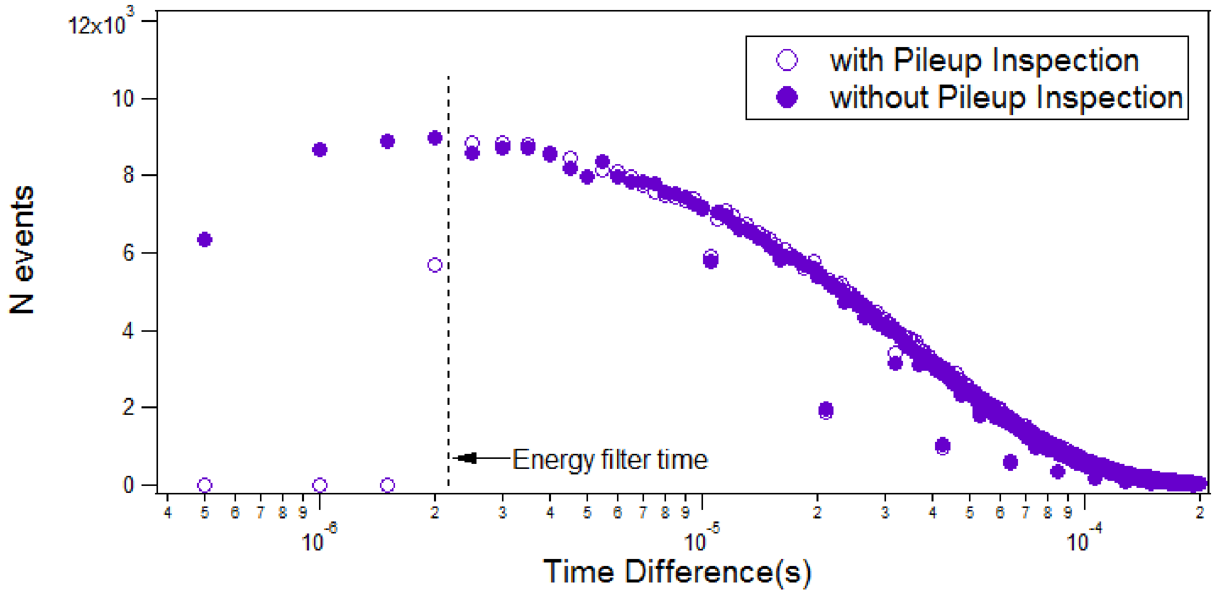

Fig.9: Histogram of time difference between subsequent events captured by the Pixie-500 Express. With pileup rejection enabled, the minimum time difference is the energy filter time. Without pileup rejection, the minimum approaches zero.

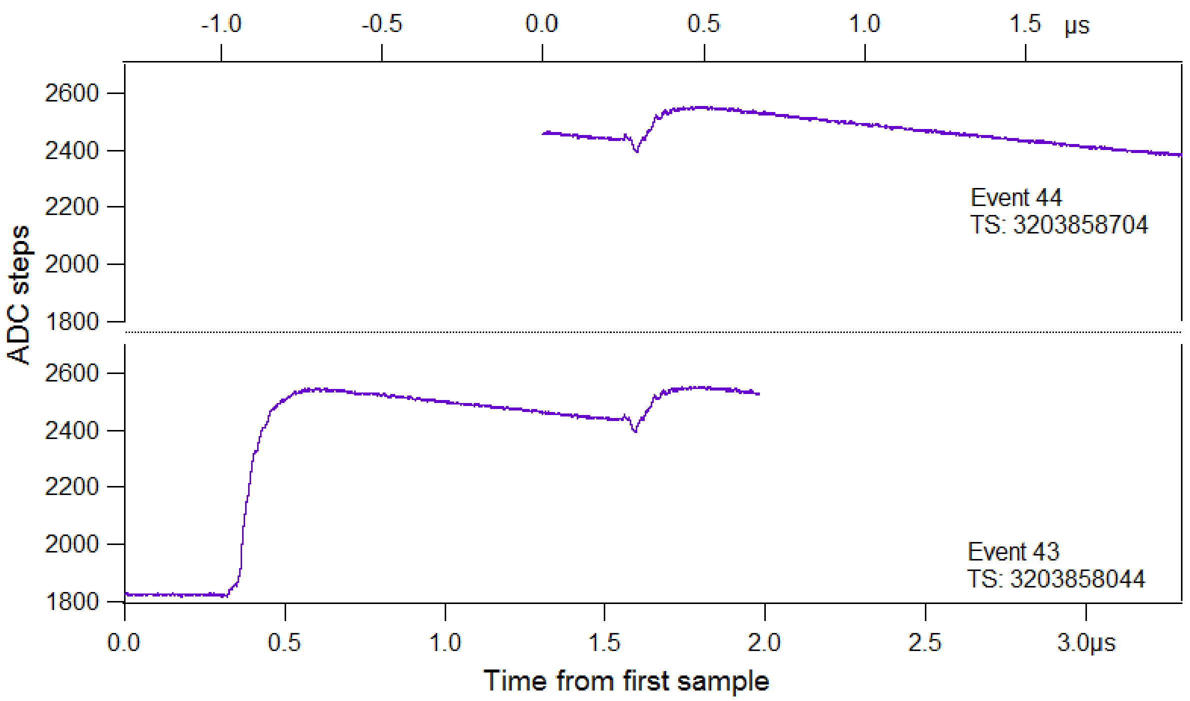

Fig.10: Capture of overlapping waveforms from closely following events with the Pixie-500e. The difference in time stamp TS is 660 clock cycles (1320 ns).