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Instruments that advance the art

High-Speed, Multi-Channel Detector Readout Electronics for Fast Radiation Detectors

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DOE Grant DE-FG02-08ER84981

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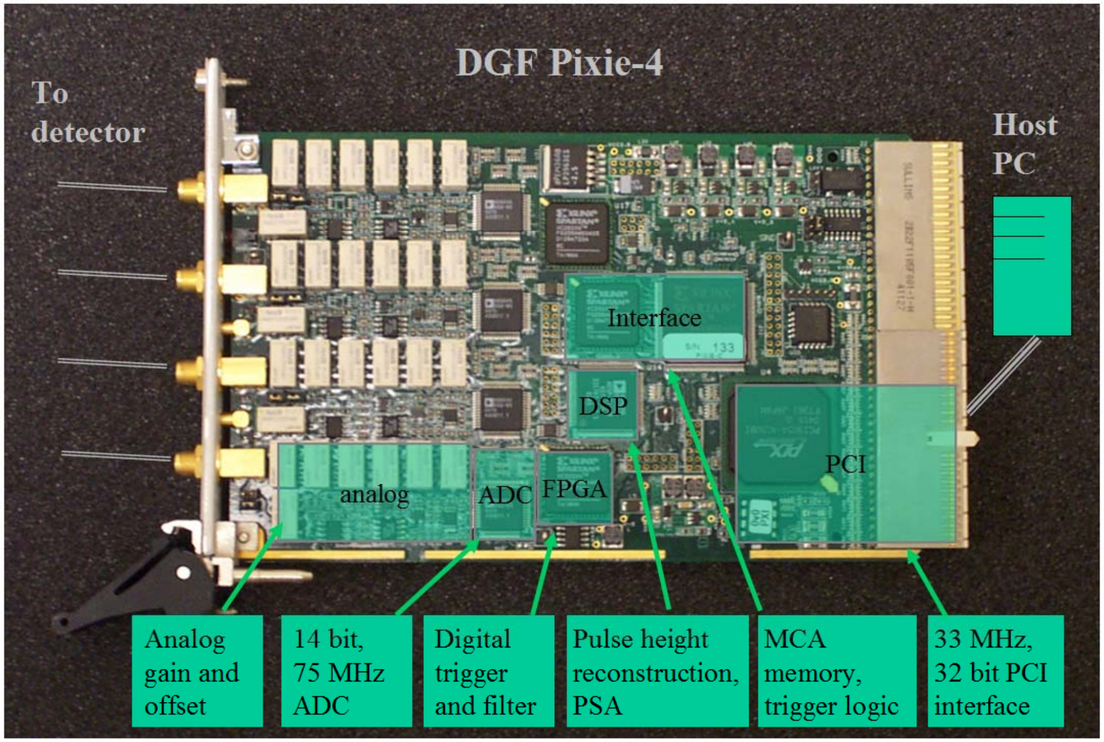
Company Background

XIA LLC (formerly X-ray Instrumentation Associates) produces advanced X-ray and gamma-ray detector electronics and related instruments with applications in research, industry, and homeland security

- Located in San Francisco Bay Area
- About 20 employees
- Products range from 2”x3” OEM circuit boards to 3’x3’x2’ detector assemblies, \$500-50,000.
- Two main product lines:
  - DGF Gamma ray processors (higher precision, coincidence, waveforms) for HPGe, scintillators, silicon strip detectors
  - DXP X-ray processors (higher throughput, fast mapping) for Si(Li), HPGe, silicon drift detectors

Products Overview

- Aim to replace analog multi-module electronics with all-digital pulse processing in DSP and/or FPGA.
- Early products were pulse processing modules based on CAMAC standard, now most instruments are based on PXI standard or are standalone USB devices.



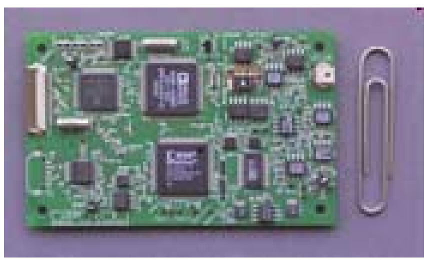
PXI:

- Common industry standard
- PCI data I/O (~100 MByte/s)
- Compact crate + module form factor
- Backplane clock and trigger lines

Products Overview

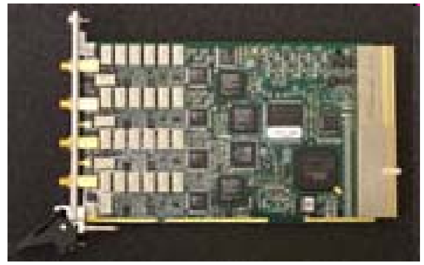
DXP xMAP

DXP Mercury

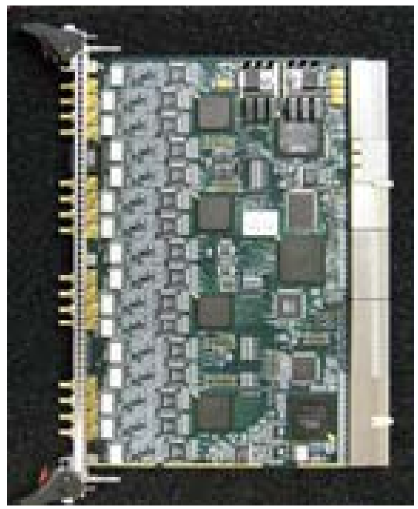


µDXP

DXP Saturn



DGF Pixie-4



DGF Pixie-16

DGF Polaris

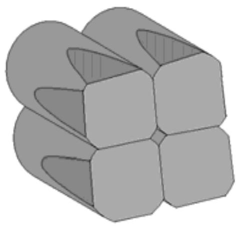
Ultra-LO 1800

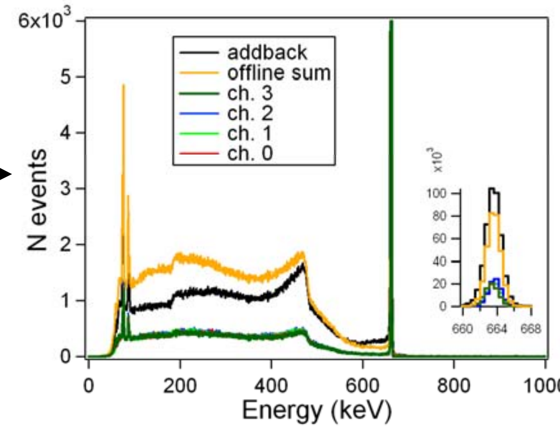
PhosWatch

DXP Mercury-4-OEM

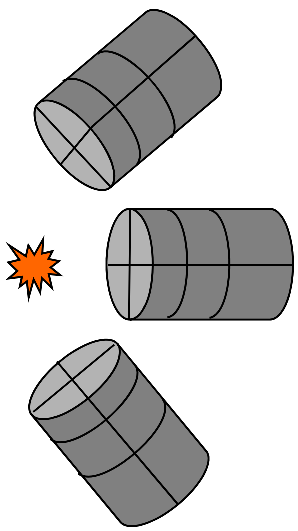
Sample Applications

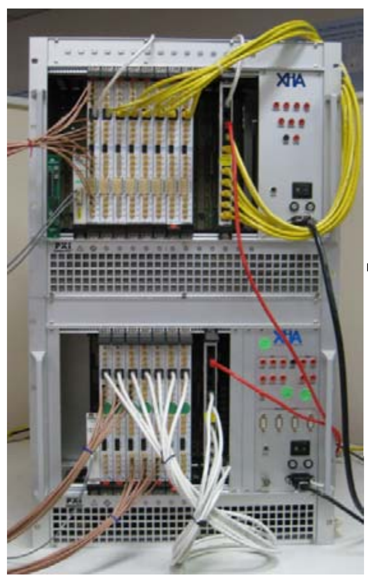
Compact clover readout system with single Pixie-4

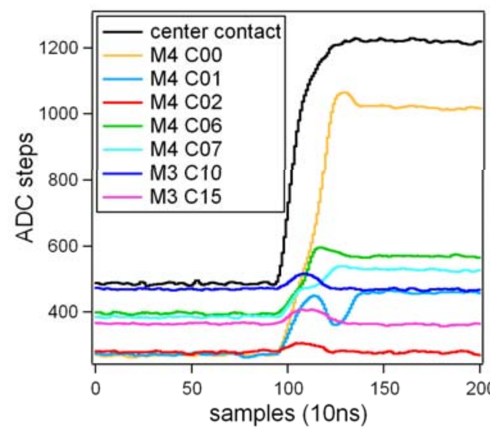




HPGe detector array, gamma ray tracking with multiple Pixie-16







Motivation

- Accelerators are upgraded for higher energies, better yields of short lifetime nuclei, higher count rates
- New/improved detectors with faster signals, better position/time/energy resolution
- ADCs with higher precision, faster rates, reasonable power now available

=> Build readout electronics matching these improvements

SBIR Project Objectives

SBIR project objective is to develop electronics with multi-channel digital pulse processing as in existing products, but additionally

- Waveform capture at 12 bit, 500 MHz
- High throughput
  (more processing in FPGA, ≥ 250 MHz DSP)
- High speed readout to host PC
  (PXI Express x4 ≤ 1GByte/s -- per slot)
- "Zero dead time" data flow
  (large FIFO buffer with DRAM)

Technical Approach

SBIR Phase	Tasks	Module Name	Status
I	Upgrade Pixie-4 with high speed ADC, demonstrate waveform capture	P500	Done
I	Initial characterization of P500 performance (mostly offline)		Done
II	Implement online pulse processing firmware on P500, full characterization		Done
	Revise P500 and release as commercial product	Pixie-500	Done
II	Design fully featured prototype (same high speed ADC, better DSP, PXI Express)	Pixie-500 Express	Finishing up
II	Implement basic FPGA processing for Pixie-500 Express		In progress
II	Update Pixie host driver software		Finishing up
II	Develop additional ROOT interface		Starting
II	Implement advanced processing for Pixie-500 Express (ZDT, high throughput)		

Prototype Results: Overview

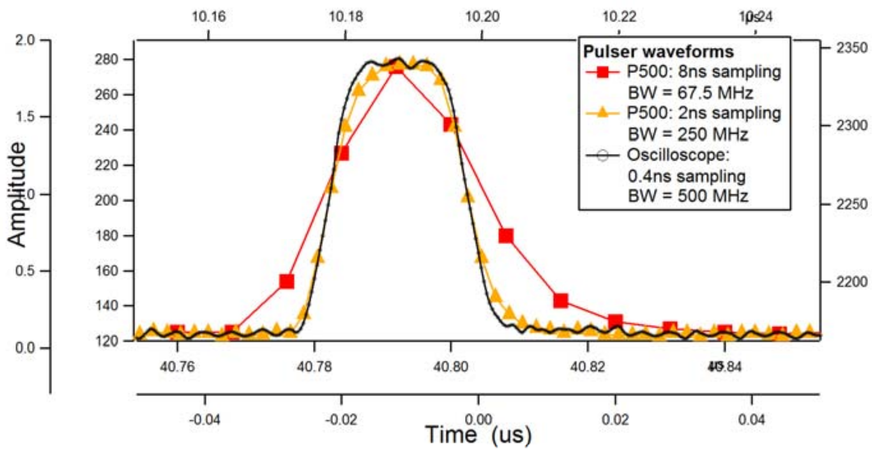
First prototype (P500) was built in Phase I to demonstrate the FPGA can handle 500 MHz data (key requirement).

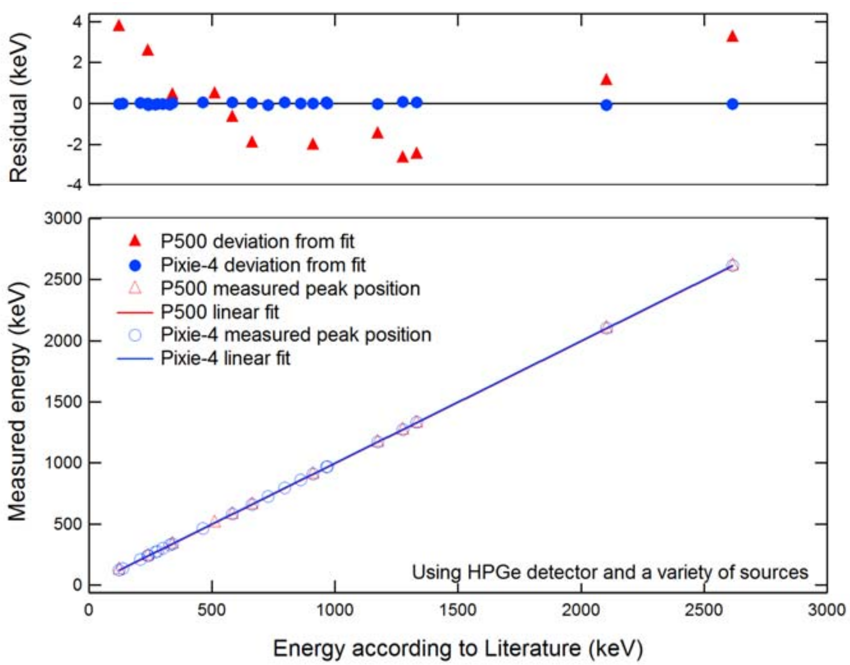
Some tests conducted at end of Phase I

Phase II started with full performance characterization to find changes necessary for commercial quality spectrometer

- ADC characterization
- Energy Resolution
- Timing Resolution
- Pulse Shape Analysis

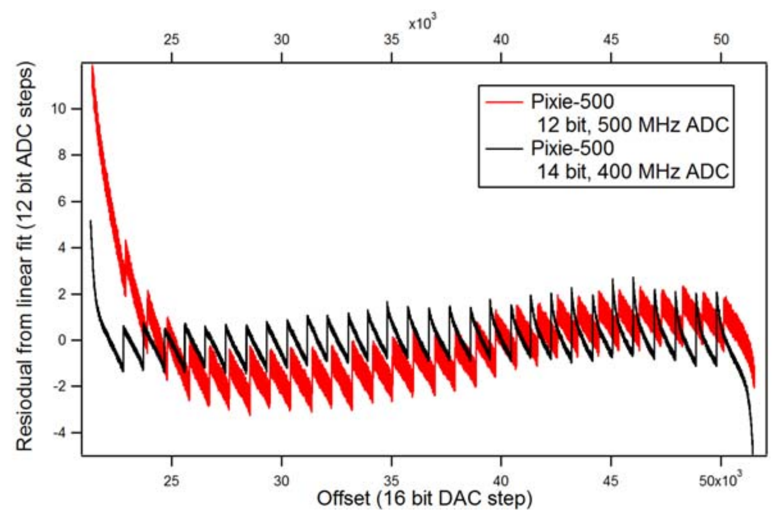
Prototype Results: ADC characterization



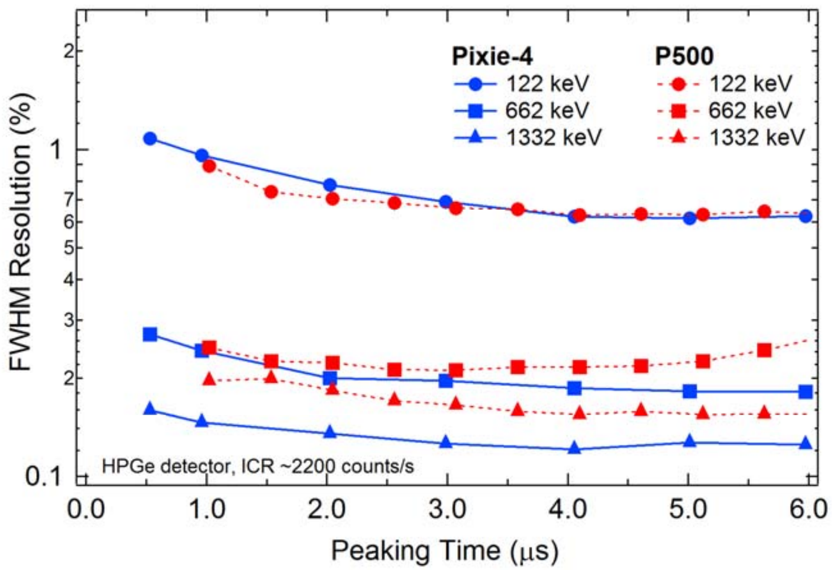


- Nonlinearity
- Noise
- Distortion

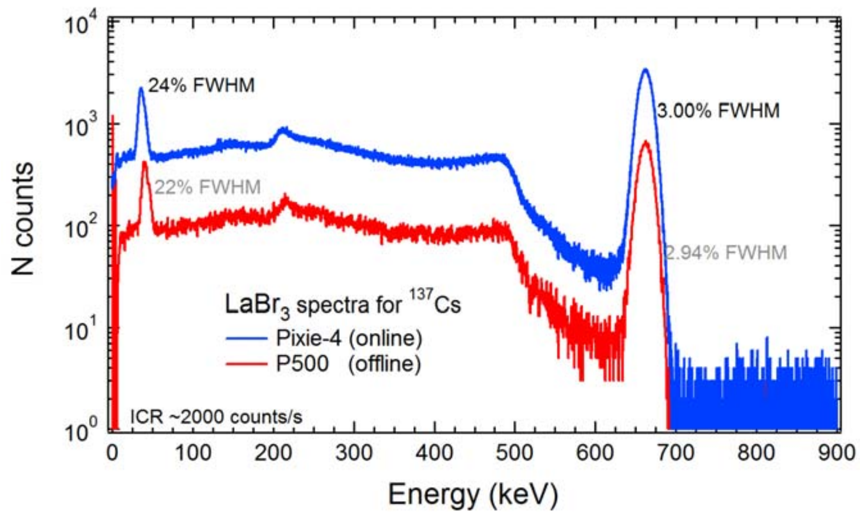
$\Rightarrow$ Overall acceptable

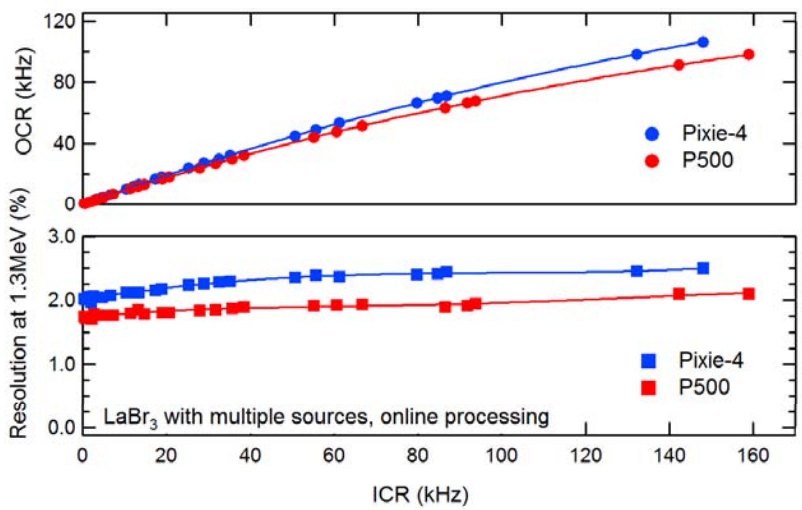


Prototype Results: Energy Resolution

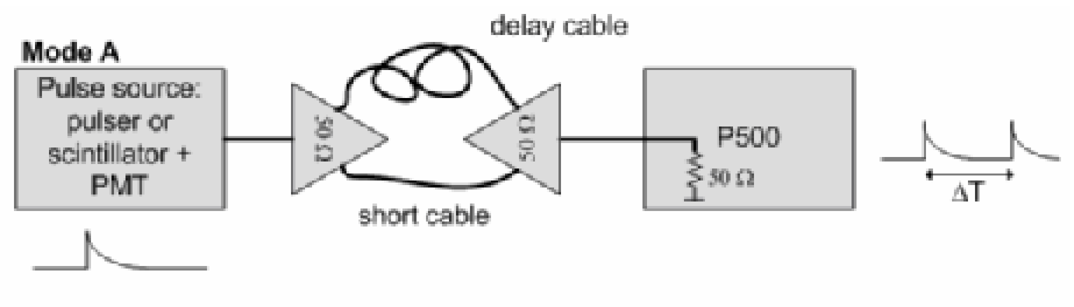


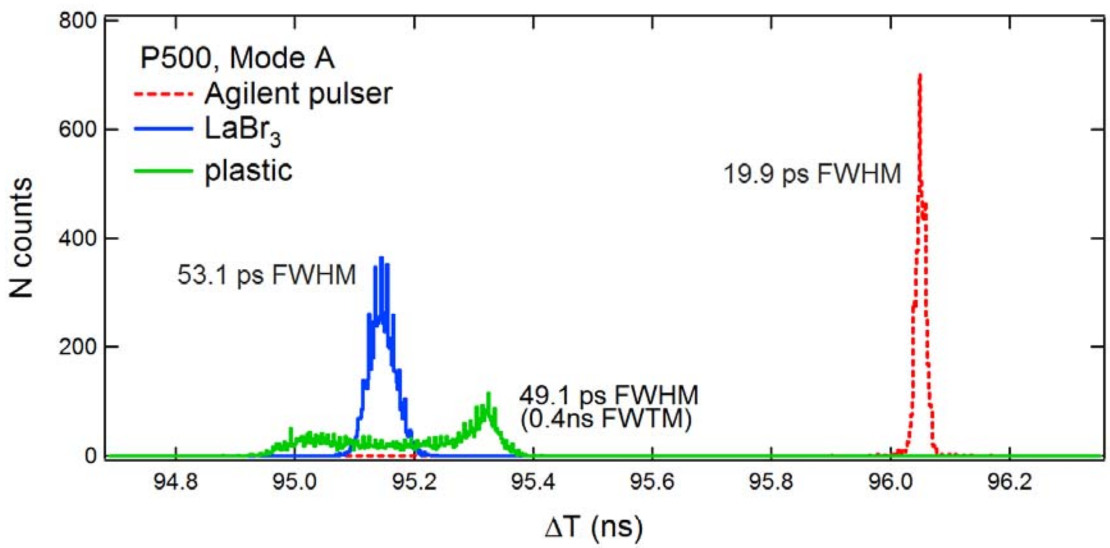
- Used with HPGe detector, P500 resolution is somewhat worse than Pixie-4, as expected
- No resolution penalty with lower resolution fast detectors (e.g. $LaBr_3$) which are the main target application





Prototype Results: Timing Resolution





Measured ΔT between two rising edges in several configurations, then histogrammed ΔT for many events

<u>Configurations:</u>

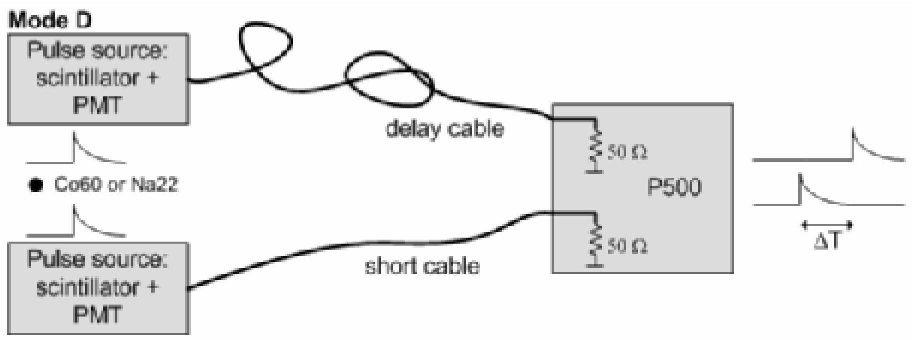
A-Split pulse, single channel

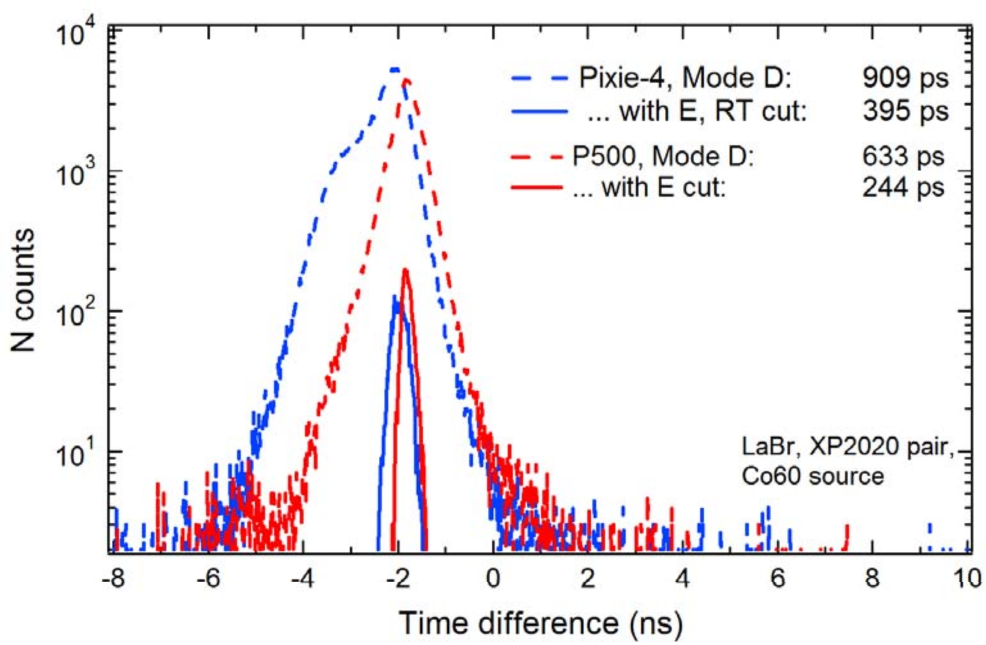
B-Split pulse, two channels

C-Split pulse, two modules

- With pulser, P500 time resolutions are 20-40 ps FWHM in configurations A-C
- With $LaBr_3$ (“real source” jitter): 23-100 ps

Prototype Results: Timing Resolution





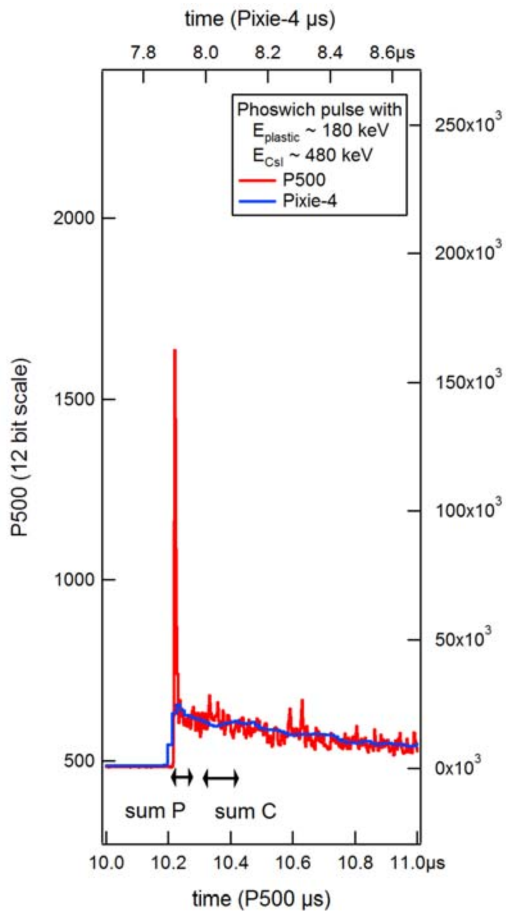
Configuration D

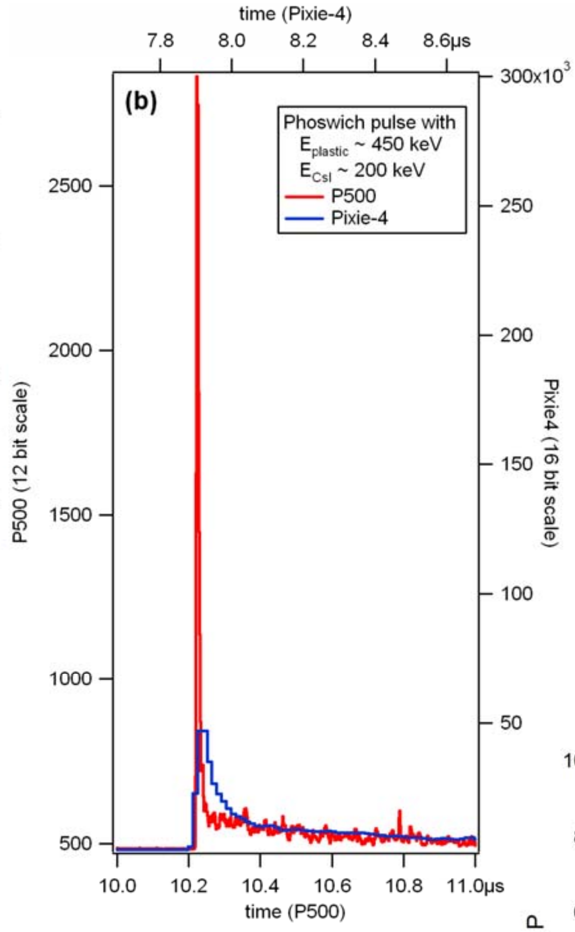
Coincident pulses, two channels

- P500 time resolution is ~250ps for E > 1 MeV
- Corresponds to ~177ps FWHM per PMT channel

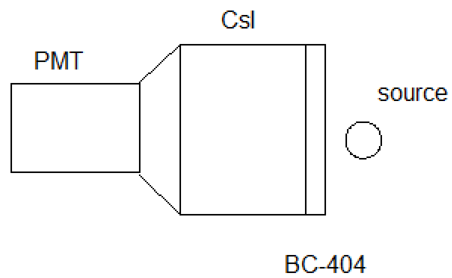
  (literature: ~140ps with analog system and faster PMT)
- Pixie-4: a few hundred ps in all modes even with pulser

Prototype Results: Pulse Shape Analysis

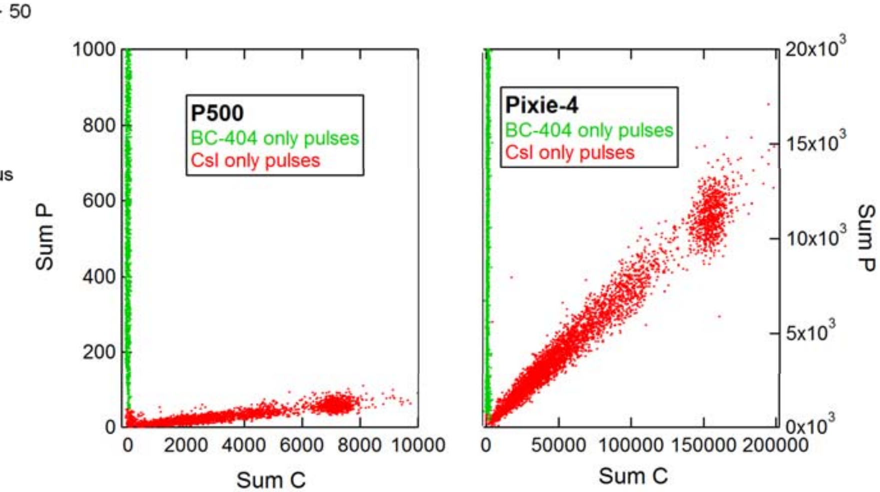




BC-404/CsI phoswich



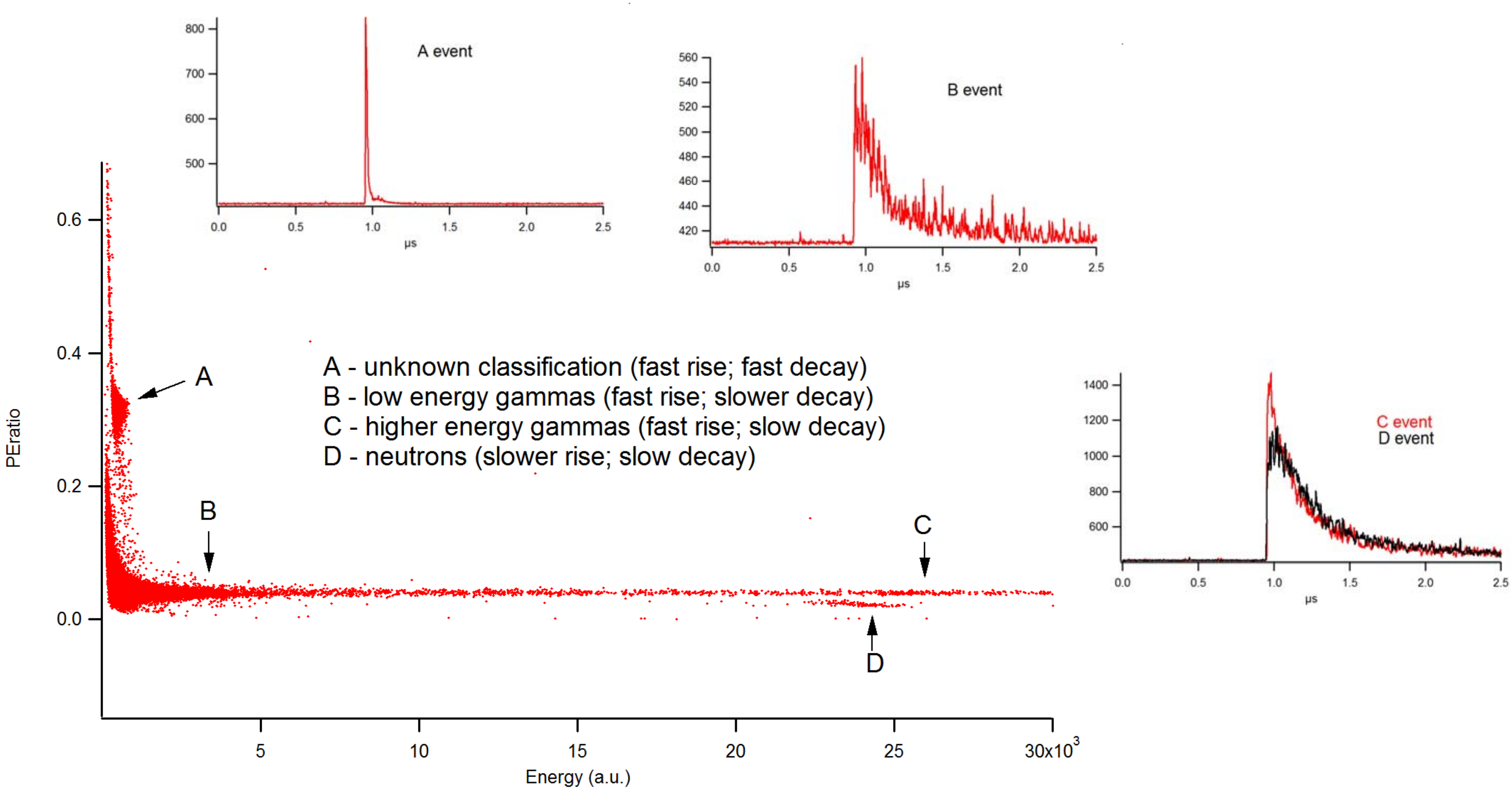
Total energy deposited is 662 keV in all shown waveforms, scattering from BC-404 to CsI



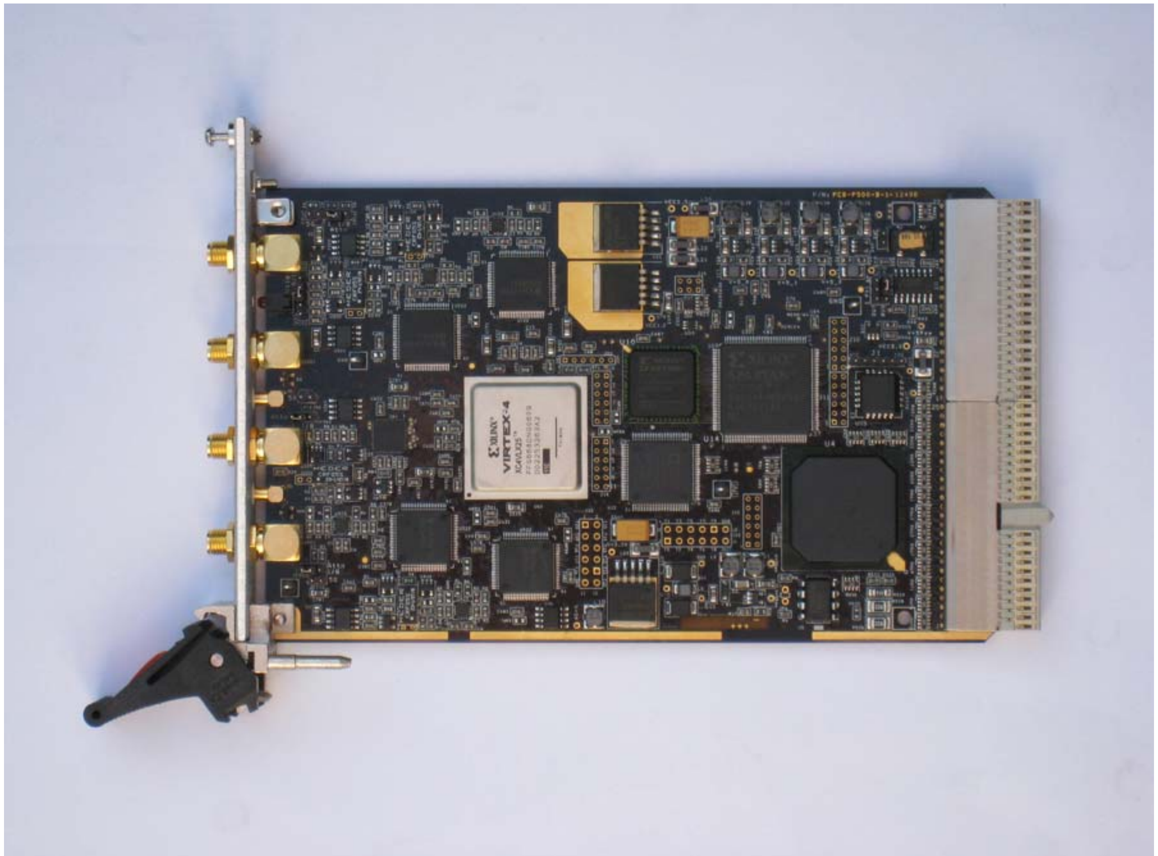
- Higher bandwidth resolves fast plastic component much better, esp. for lower energies
- Event types can be better separated

Pulse Shape Analysis: CLYC

- More recently: Tested Cs_2LiYCl_6:Ce scintillator
- Crystal courtesy of RMD



First Commercial Module: Pixie-500



- Good performance, no major changes required
- Strong interest at conferences* etc

⇒ Released (updated) prototype as commercial product

… already sold several modules

PXIe Module Development

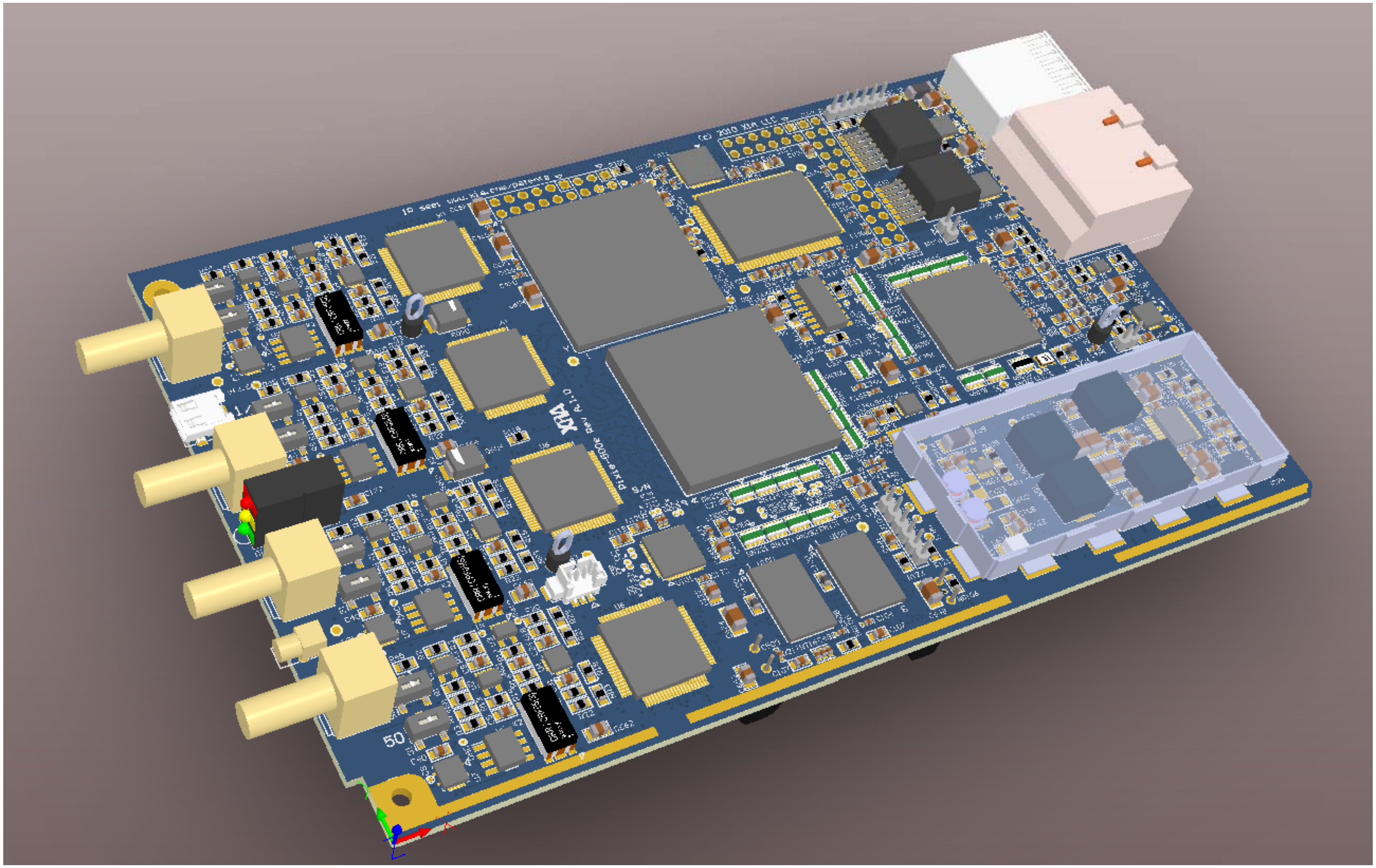
Preliminary Specifications for Pixie-500 Express

- Up to 800 MByte/s data transfers to host (PCIe x4)
- 128 MByte SDRAM List mode memory (~6 million events)
- 12 bit, 500 MHz or 14 bit, 400 MHz ADC
- 512 K channels of MCA memory (online 2D spectra)
- 100 MHz logic I/O
- 250 MHz, 32 bit floating point DSP

Challenges in PXIe design

- Limited power provided by PXIe standard
- Complex host data I/O (packets)
- High speed signal PCB layout (controlled impedances, matched delays)
- Limited vendor support for firmware (simulation models)
- Complex DRAM control logic

PXIe Module Development



Summary and Outlook

- Built 500 MHz spectrometer prototype
- Characterized performance
  Energy resolution: <0.2% @ 1.3 MeV with HPGe
  Timing resolution: 20ps-40ps with pulser
  Pulse shape analysis: significant improvements
- Upgraded prototype to a commercial module
- Finished design of fully featured PXI Express module
- Working on firmware and GUI

➢ Future SBIR work includes firmware improvements for high throughput

➢ Post SBIR work may include lower cost, higher channel modules for specific applications