XIA LLC
31057 Genstar Rd.
Hayward CA 94544
Phone: (510) 401-5760
FAX: (510) 401-5761

Instruments that advance the art

High Rate Digital Signal Processing for Multi-Channel Microcalorimeters

Project PI: Hui Tan

DOE Grant DE-FG02-07ER84760

XIA LLC
31057 Genstar Rd, Hayward, CA 94544, USA

Outline

1. Company Information
2. Introduction of Microcalorimeters
3. Motivation & Project Goals
4. Hardware Development
5. Pulse Processing Algorithm Development
6. Summary & Outlook

Company Information

1. Digital Gamma-Ray Spectrometers (DGF)

   Pixie-500, Pixie-16, Pixie-4, Polaris, etc.

2. Digital X-Ray Spectrometers (DXP)

   xMAP, Mercury, Saturn, µDXP, etc.

3. Low background alpha-particle counter

   UltraLo-1800 (0.0001 alpha/cm^2/hr or lower)

4. Radioxenon monitoring in the atmosphere

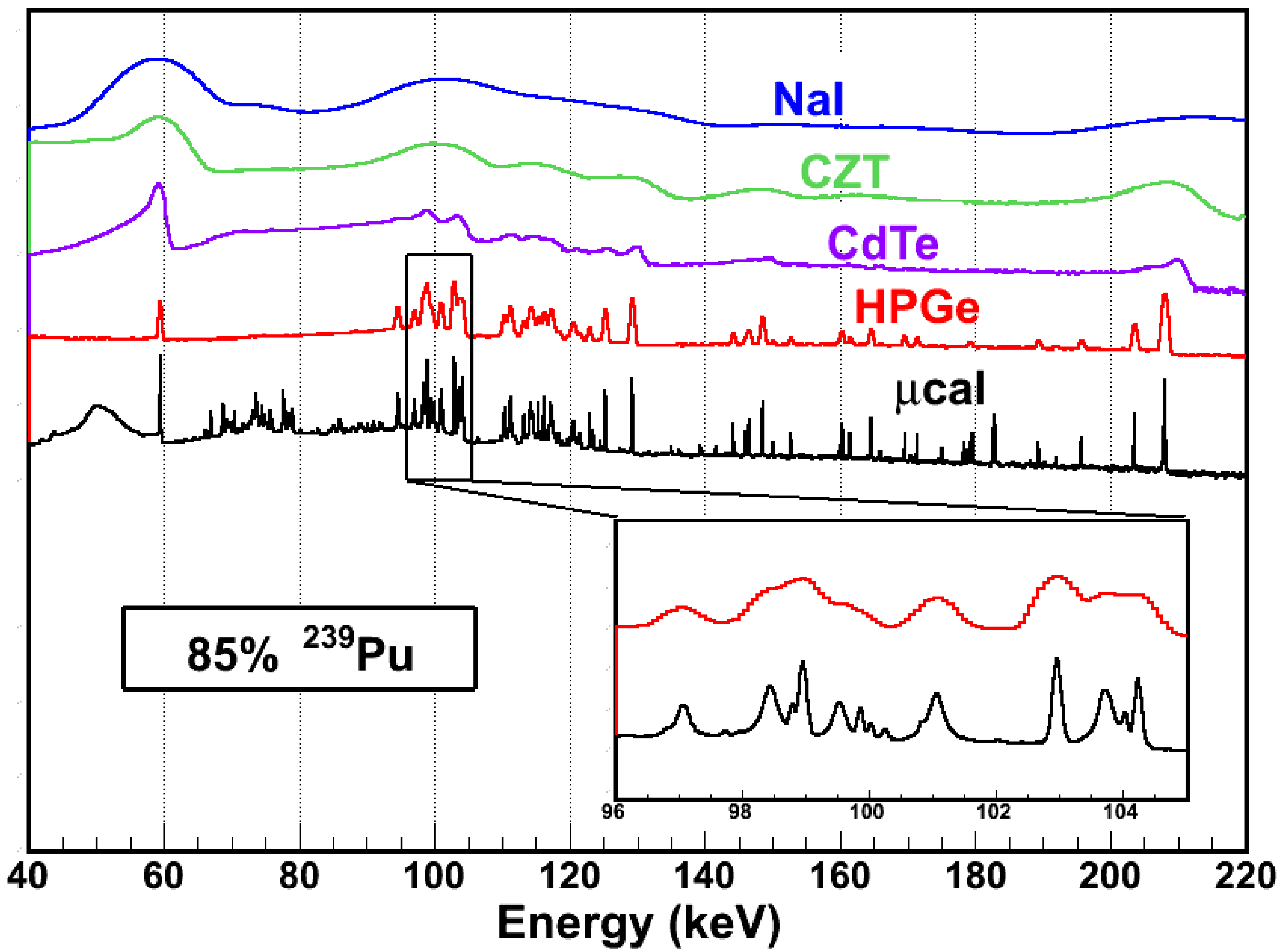
   PhosWatch - a COTS detector system

5. Electronics for low temperature detectors

   Microcalorimeters

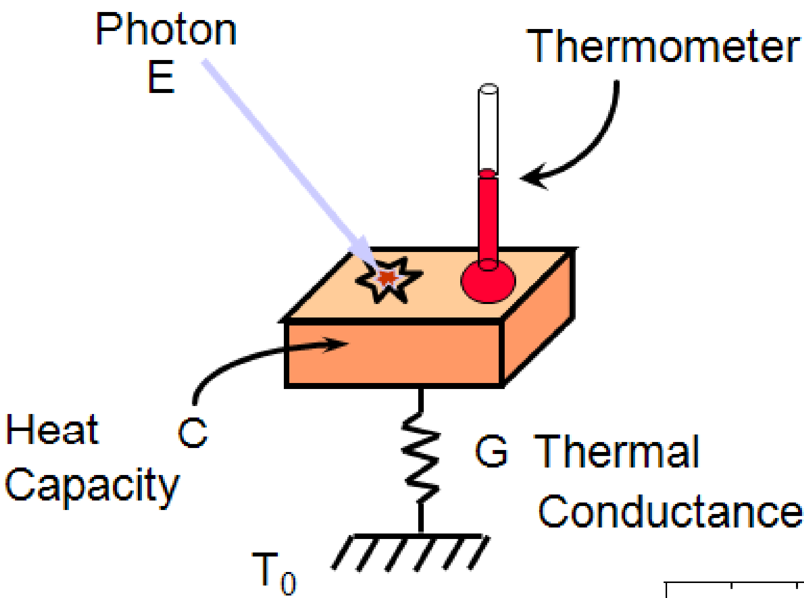
   Superconducting Tunnel Junction (STJ) detectors

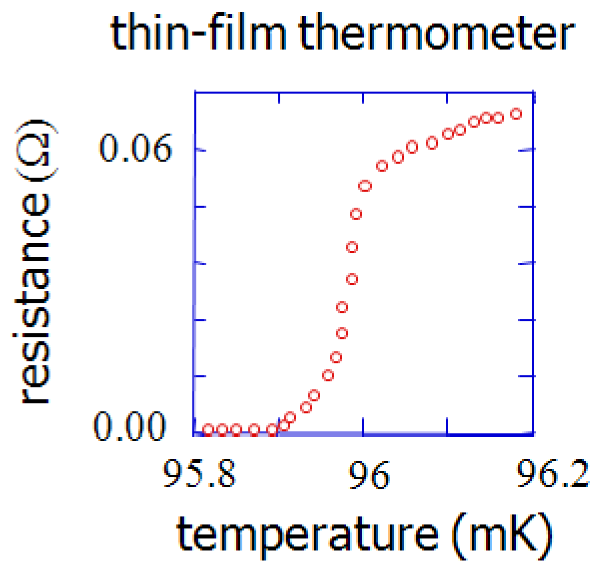
Why we need microcalorimeters?



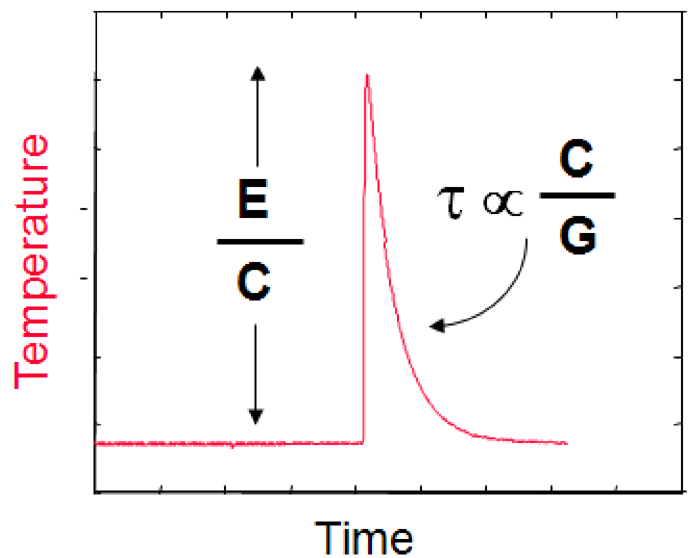
(Courtesy of N. Hoteling of LANL and J. Ullom of NIST)

What are microcalorimeters?





Thermometer choices:
Mo/Cu, Mo/Au, Ti/Au,
Al:Mn, W, Ir, …

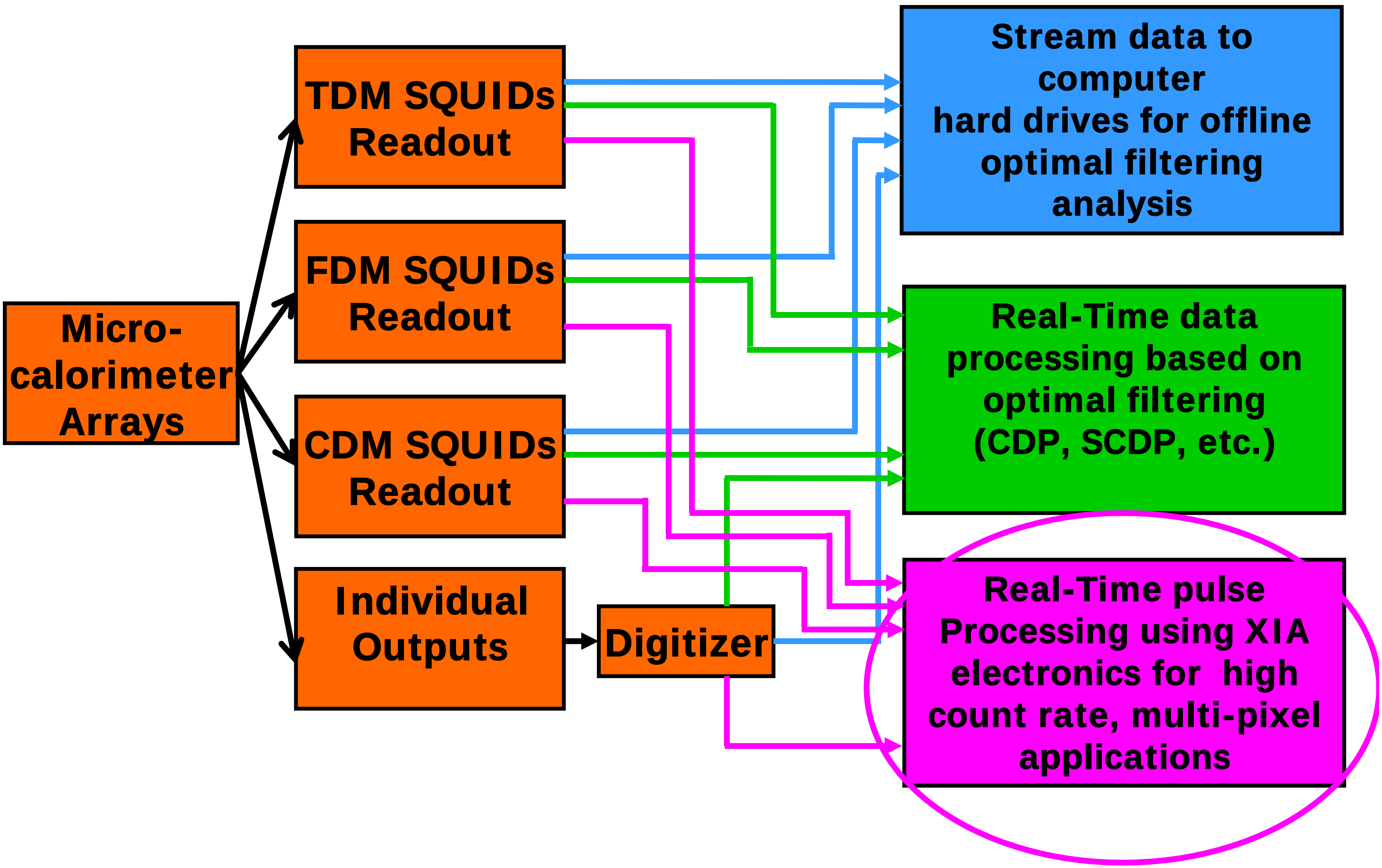


(Courtesy of J. Ullom of NIST)

Applications of microcalorimeters

- Microcalorimeters can achieve excellent energy resolutions:
  - 2 eV FWHM at 6 keV
  - 22 eV FWHM at 100 keV
  - 1 keV FWHM at 5 MeV
- Applications to a range of fields:
  - X-ray astronomy
  - materials analysis by X-ray, γ-ray, and alpha particle spectroscopy
  - dark matter detection

Motivation

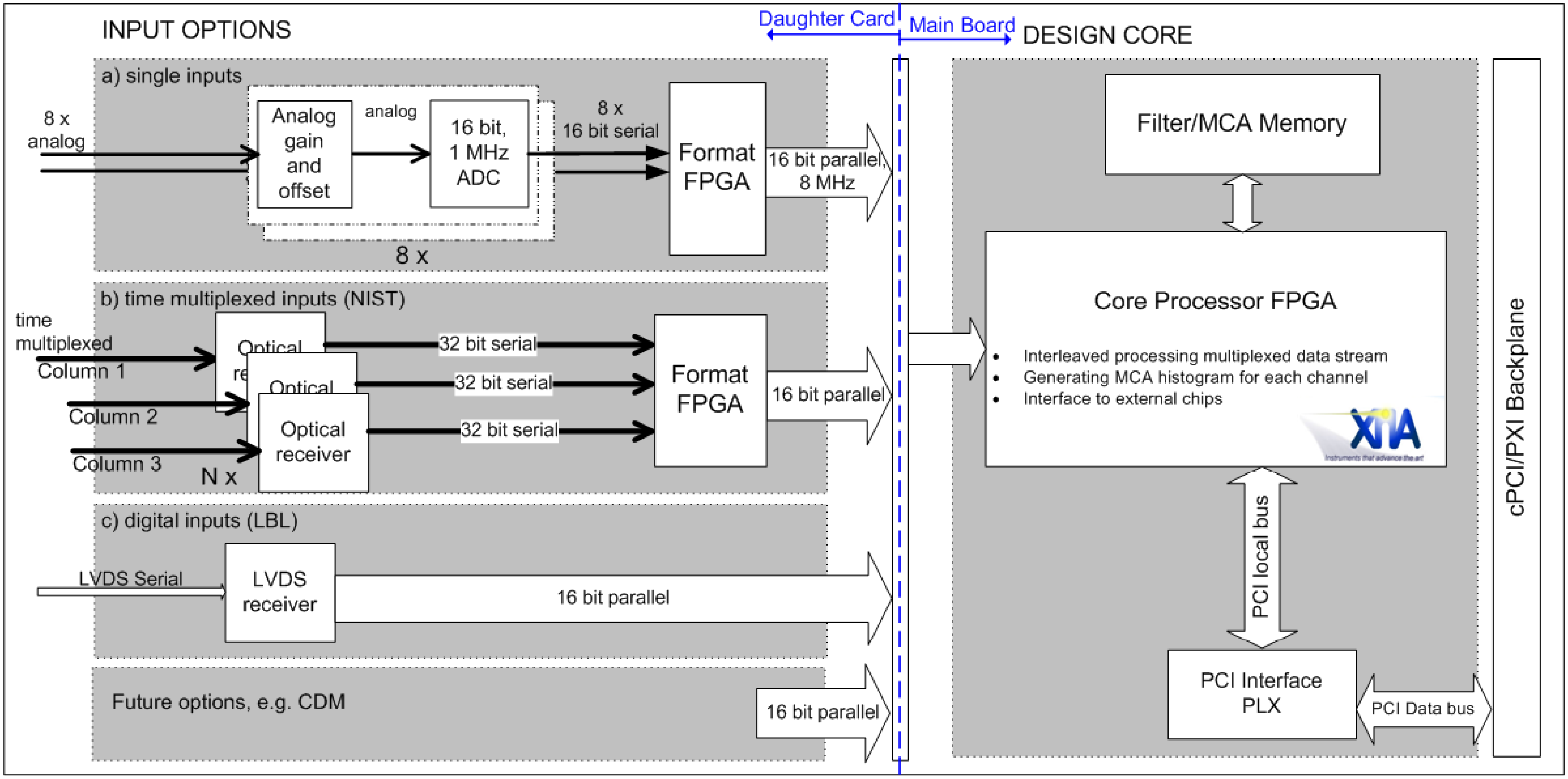


Micro-calorimeter Arrays
TDM SQUIDs Readout
FDM SQUIDs Readout
CDM SQUIDs Readout
Individual Outputs
Digitizer
Stream data to computer hard drives for offline optimal filtering analysis
Real-Time data processing based on optimal filtering (CDP, SCDP, etc.)
Real-Time pulse Processing using XIA electronics for high count rate, multi-pixel applications

Project Goals

- Develop low cost readout electronics that is capable of:
  - processing microcalorimeters pulses in real time from different readout schemes
  - achieving energy resolution that is comparable to optimal filtering results while significantly improving output count rate capability
  - automating the setup, calibration and operation of data acquisition from many channels of microcalorimeters

Technical Approach

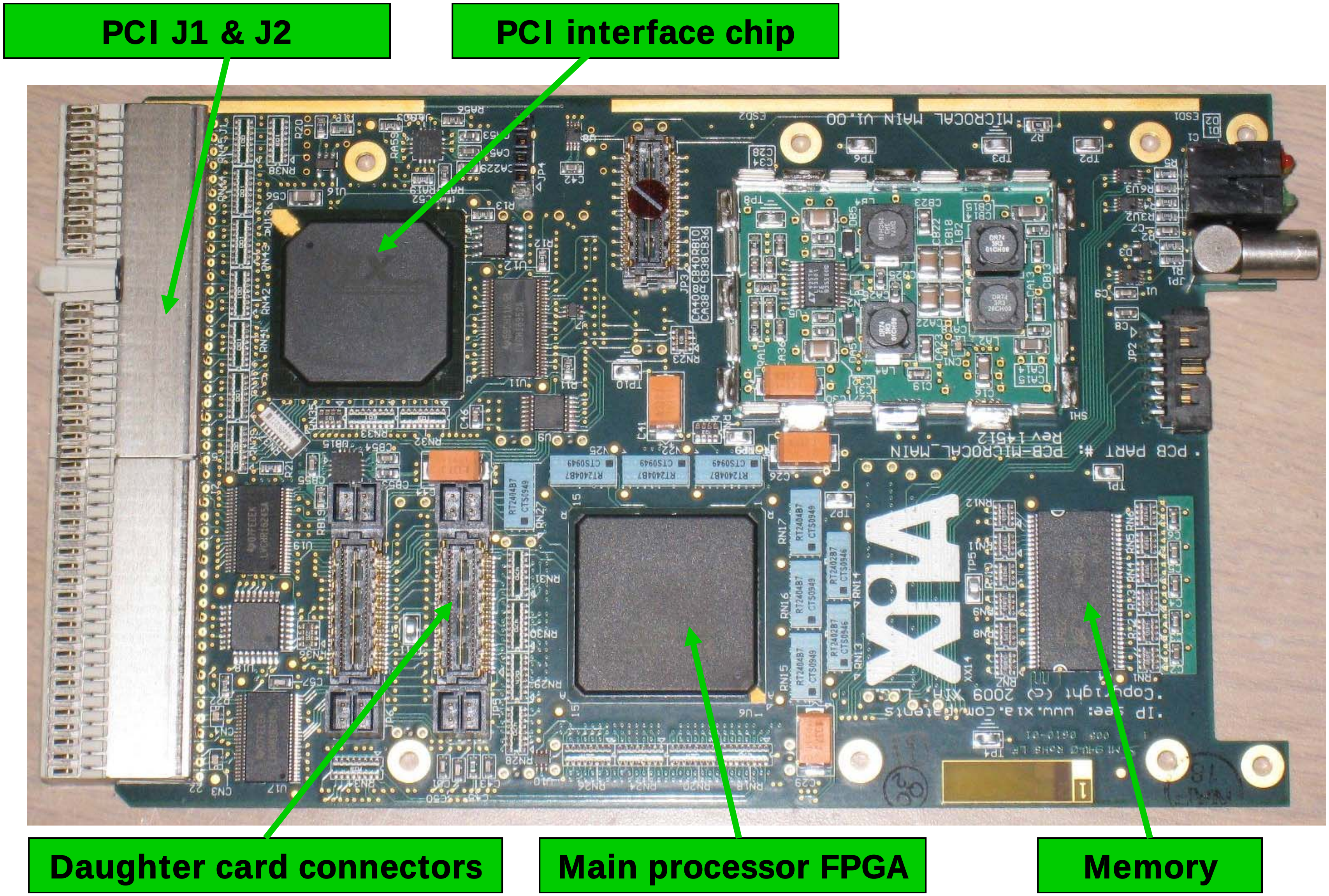


Project Tasks and Schedule

Phase II performance period: 8/15/2008 – 8/14/2010

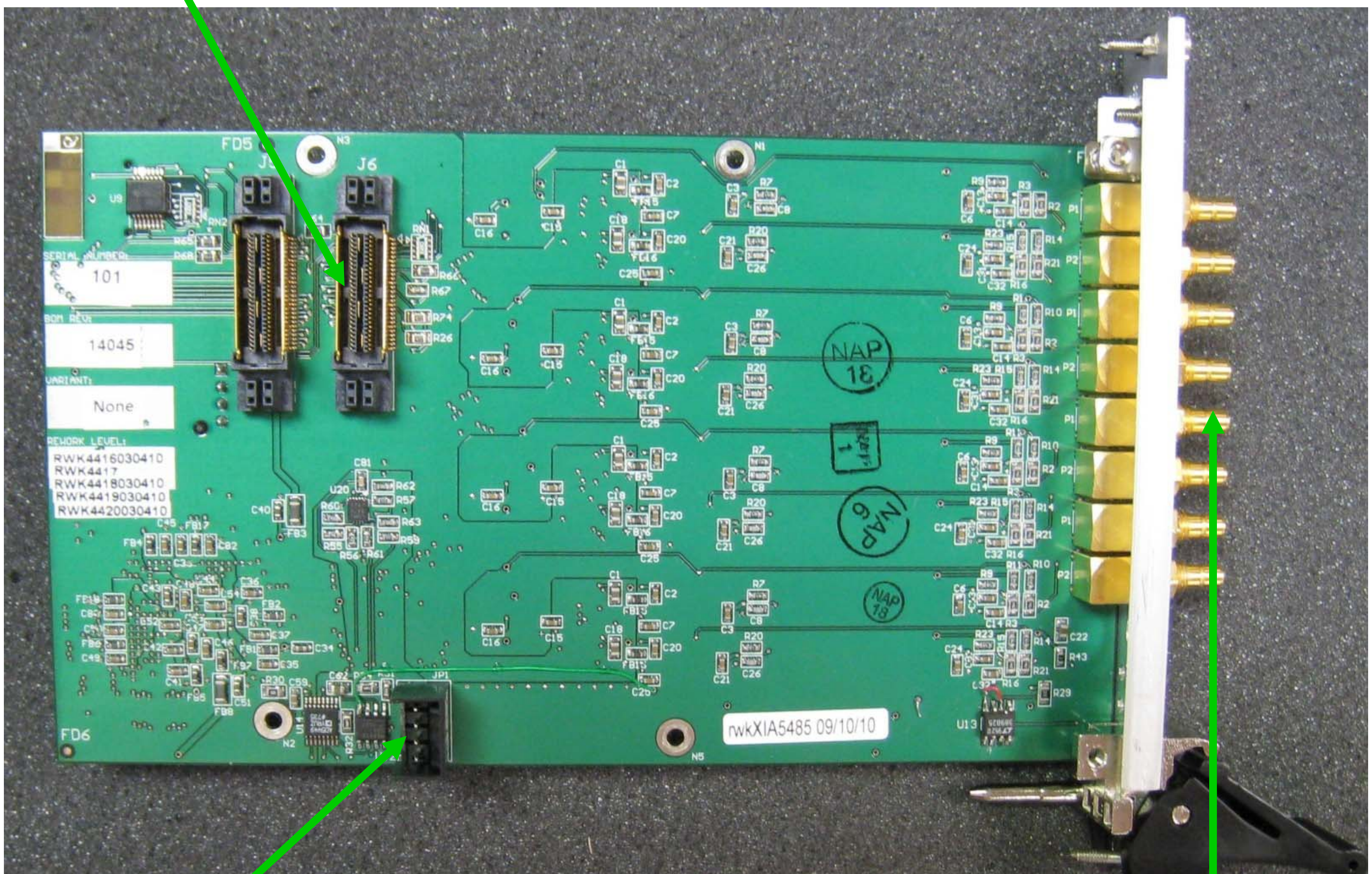
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Tasks	Status
	Task 1							Build prototype core hardware	Done
		Task 2						Build daughterboards	Done
				Task 3				Build final core hardware	Finishing up
	Task 4							Develop trigger/filter firmware	Finishing up
		Task 5						Adapt System FPGA firmware	Done
			Task 6					Adapt DSP code firmware	Done
			Task 7					Adapt host drivers	Finishing up
				Task 8				Improve algorithms for multiple decays and high count rate	Done
				Task 9				Improve algorithms for non-ideal effects	Done
					Task 10			Develop automated parameter setup	Finishing up
					Task 11			Develop system monitoring	Finishing up
				Task 12				Develop output data processing tools	Finishing up
				Task 13				Discussions with, and testing at, collaborating labs	Ongoing

XIA's Microcalorimeter Main Processor Board



XIA's Microcalorimeter AFE Daughter Card (top)

Daughter card connectors

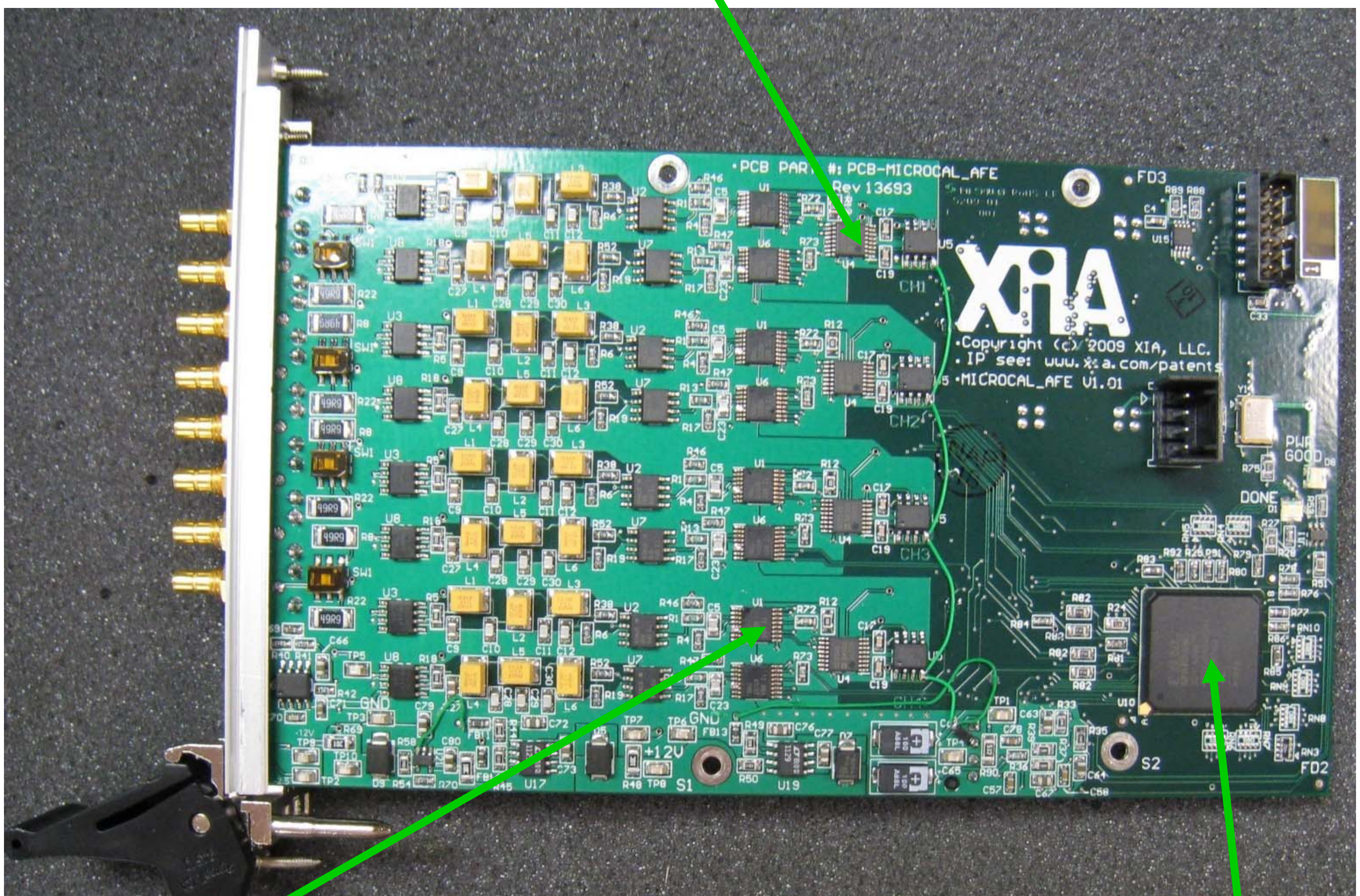


Power connectors

8 analog input signals

XIA's Microcalorimeter AFE Daughter Card (bottom)

Offset DACs (4)

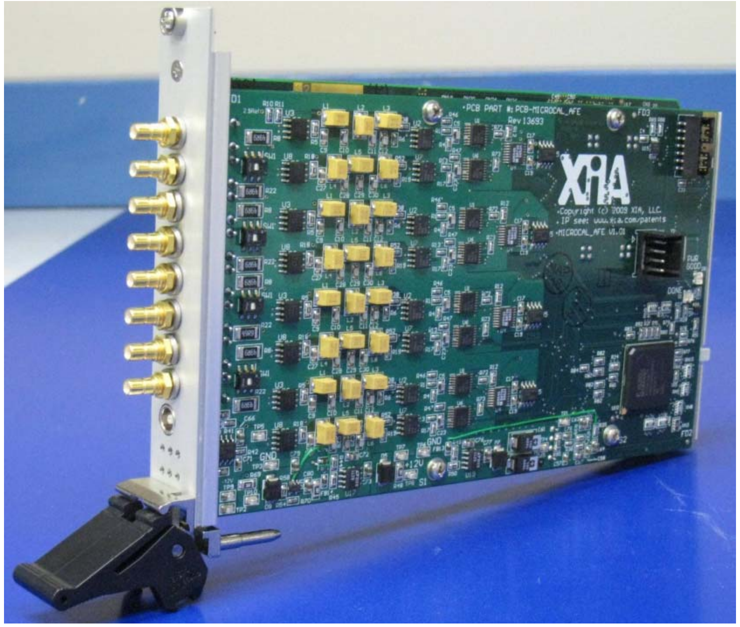


1 MHz, 16-bit ADCs (8)

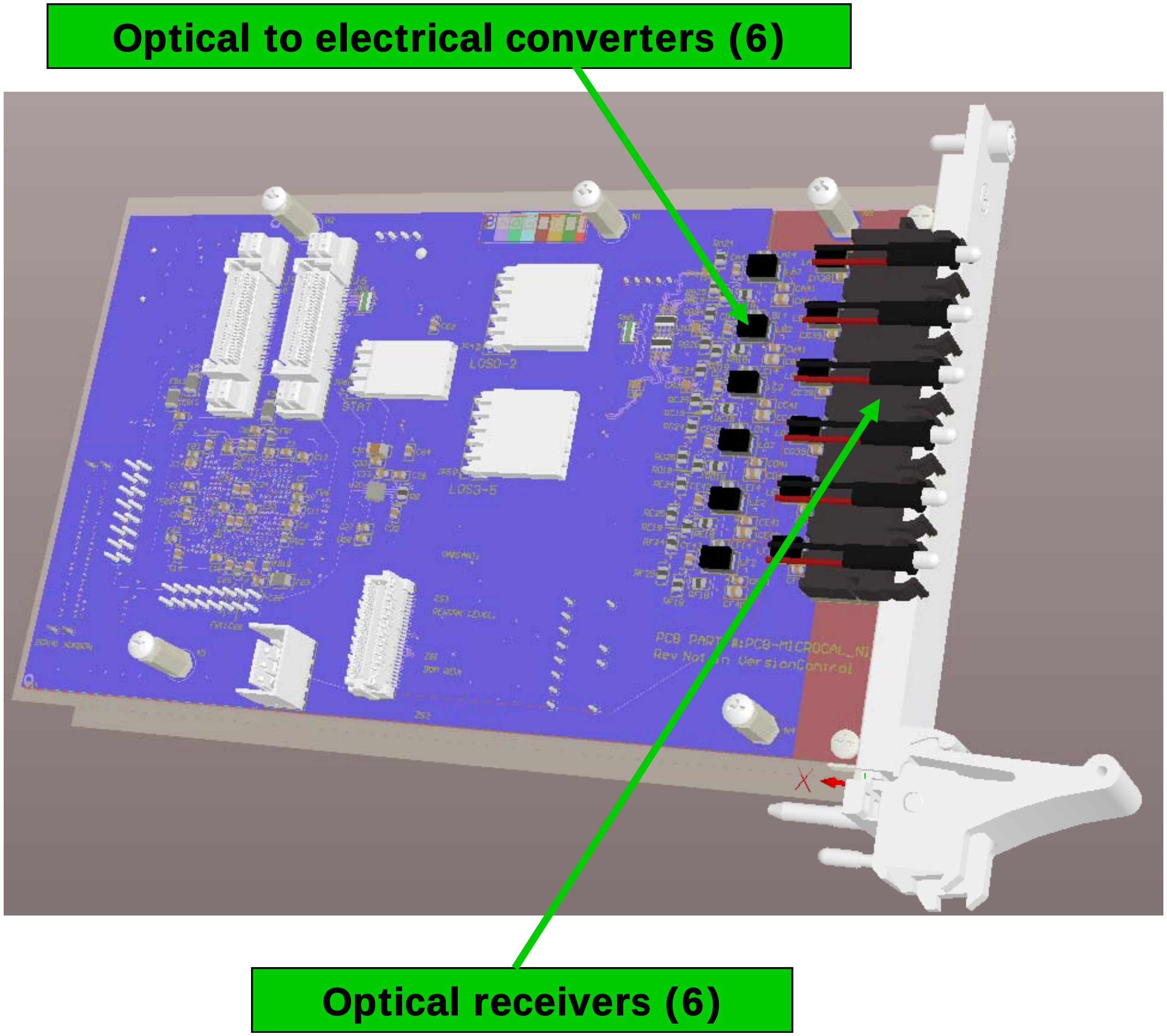
FPGA

Main Processor Board + Daughter Card Combo

- 8-channel individual-inputs daughter card coupled to main processor board
- 3U compact PCI/PXI format

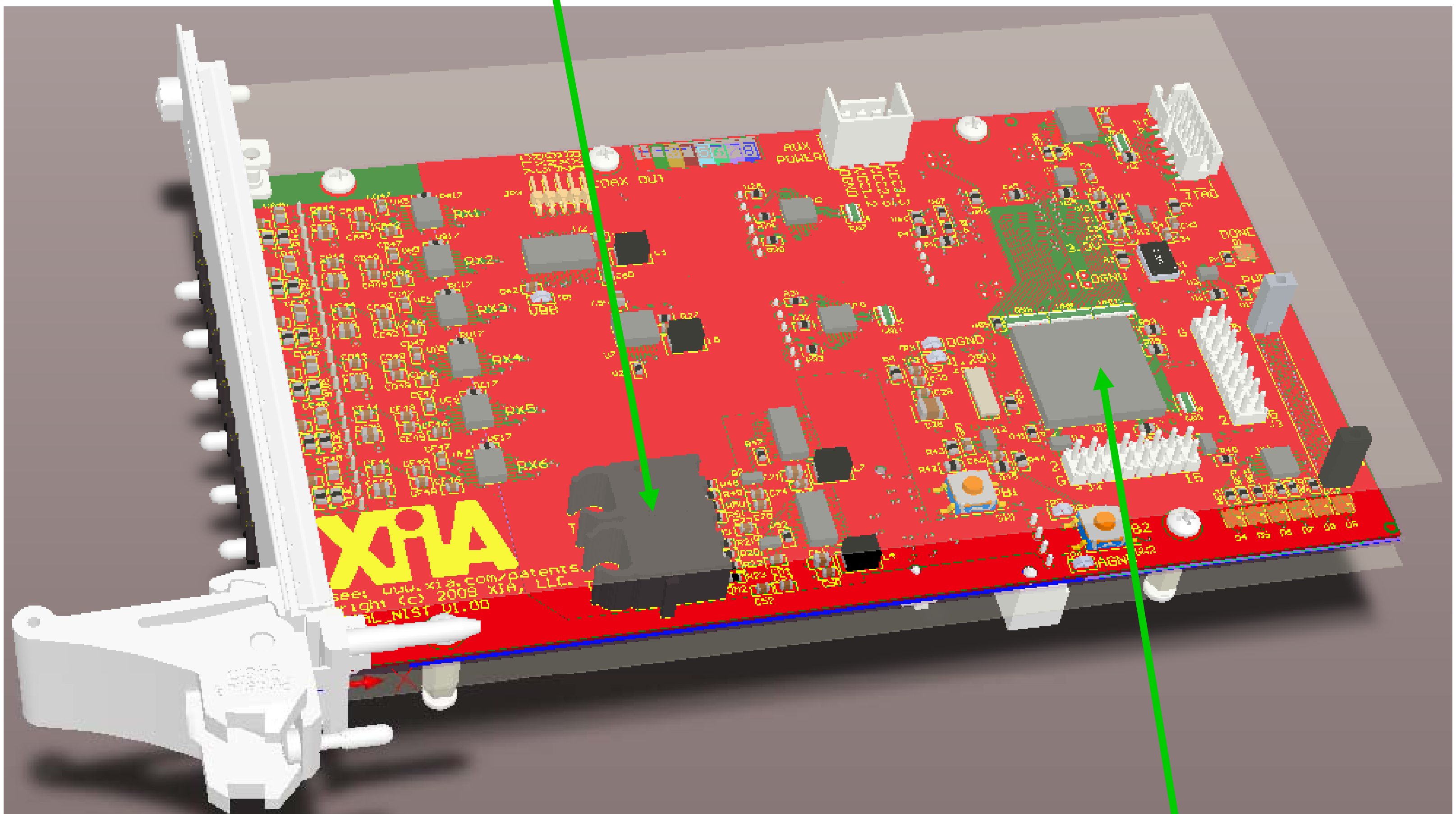


XIA's Microcalorimeter NIST Daughter Card (top)



XIA's Microcalorimeter NIST Daughter Card (bottom)

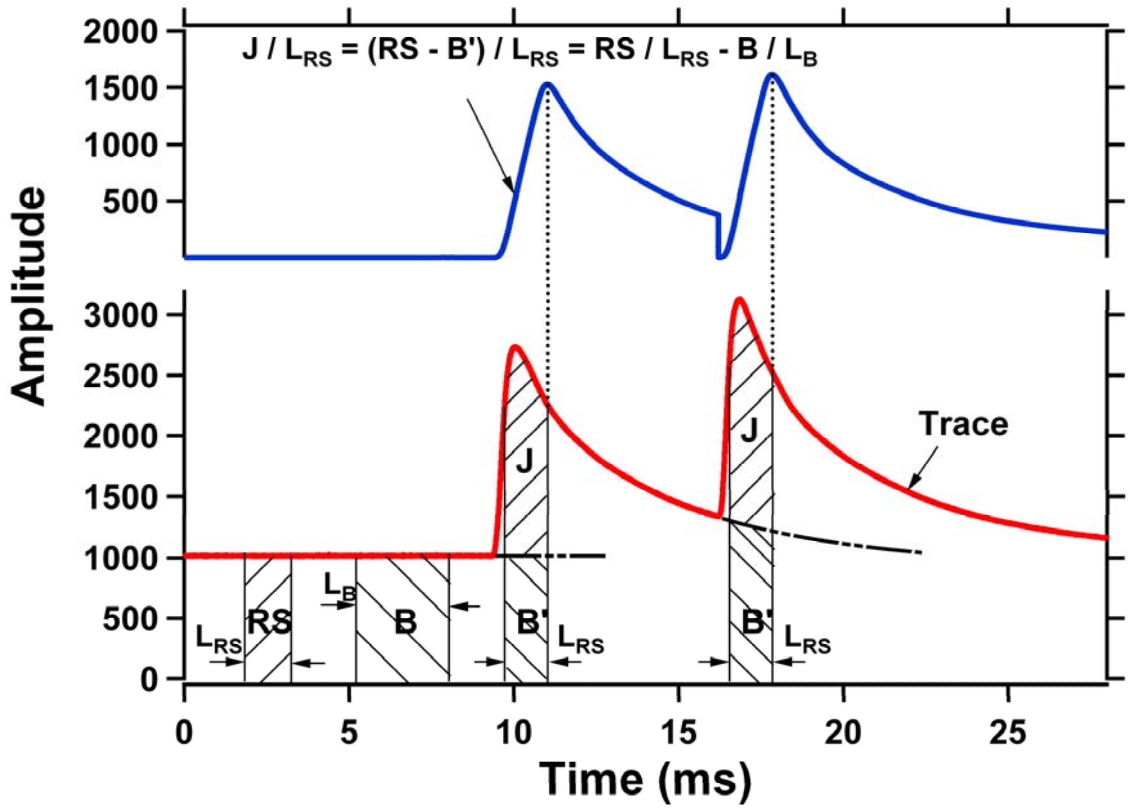
Optical transmitters for on-board optical test signals (2)



FPGA

Microcalorimeter Pulse Processing Algorithms

XIA Filter

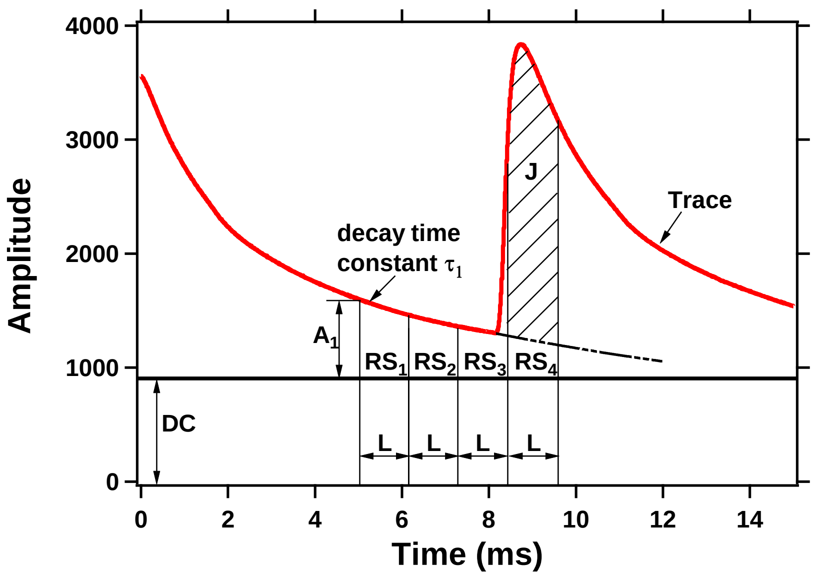


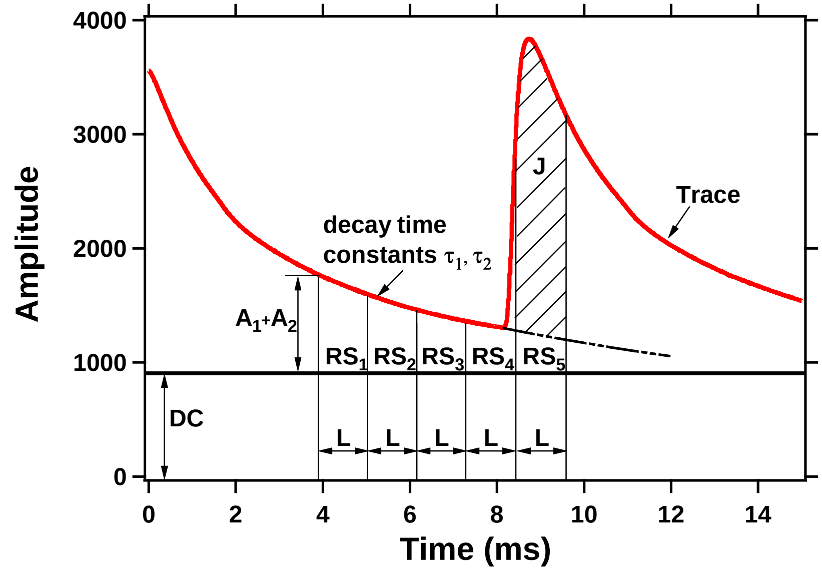
Optimal Filter

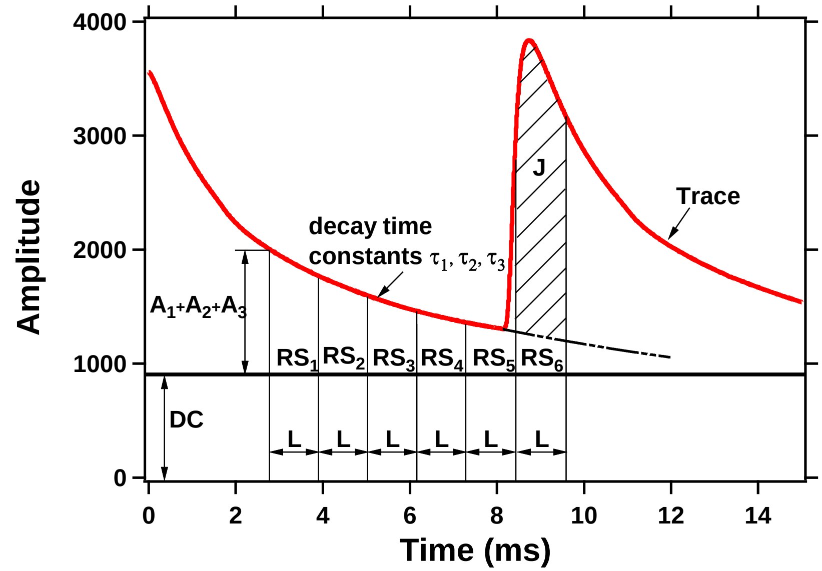
- An established technique for measuring microcalorimeter pulse height
- Requires well-separated pulses, i.e., can't handle overlapping pulses
- Output count rate capability limited

Microcalorimeter Pulse Processing Algorithms

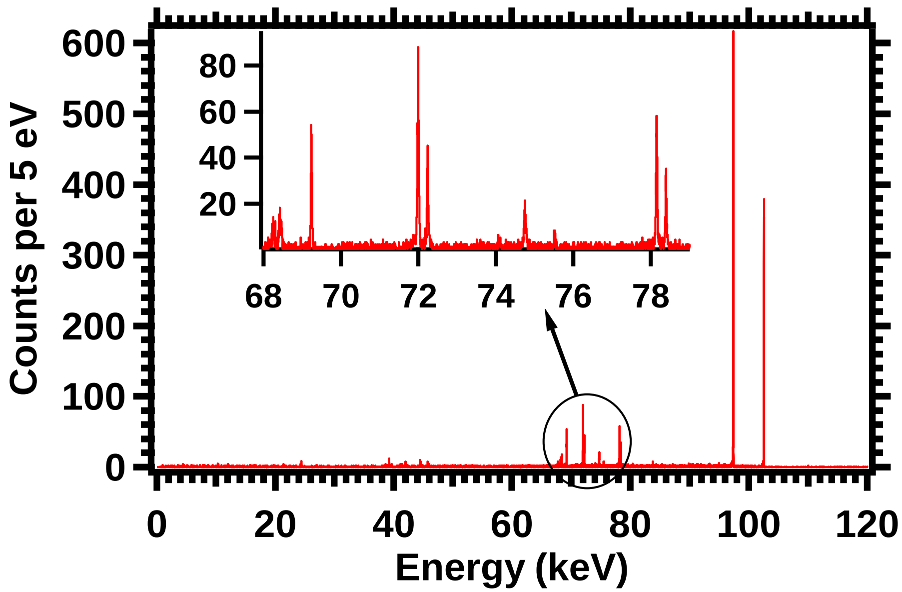
XIA Filter

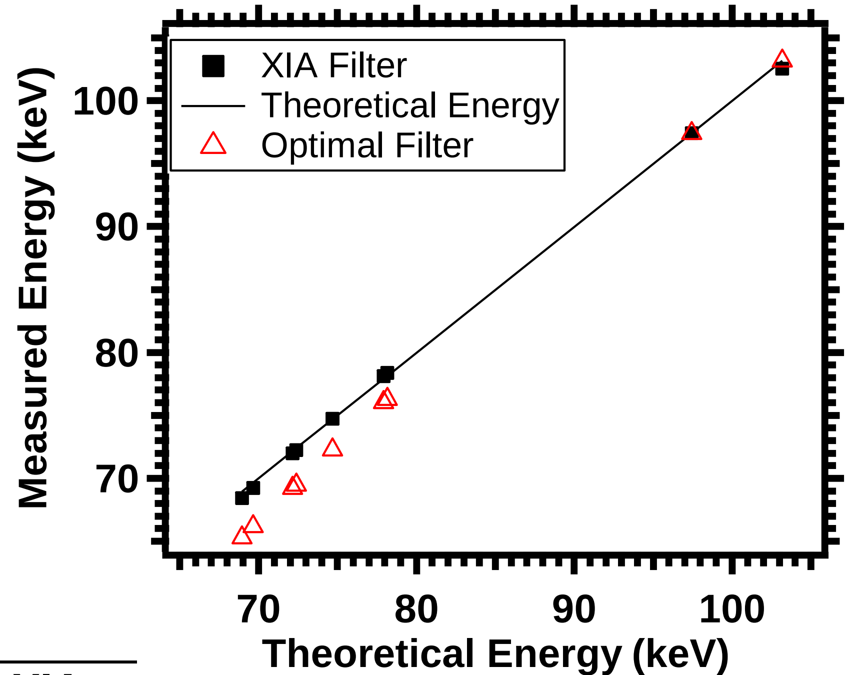






XIA Filter Results: TES Gamma-ray detectors

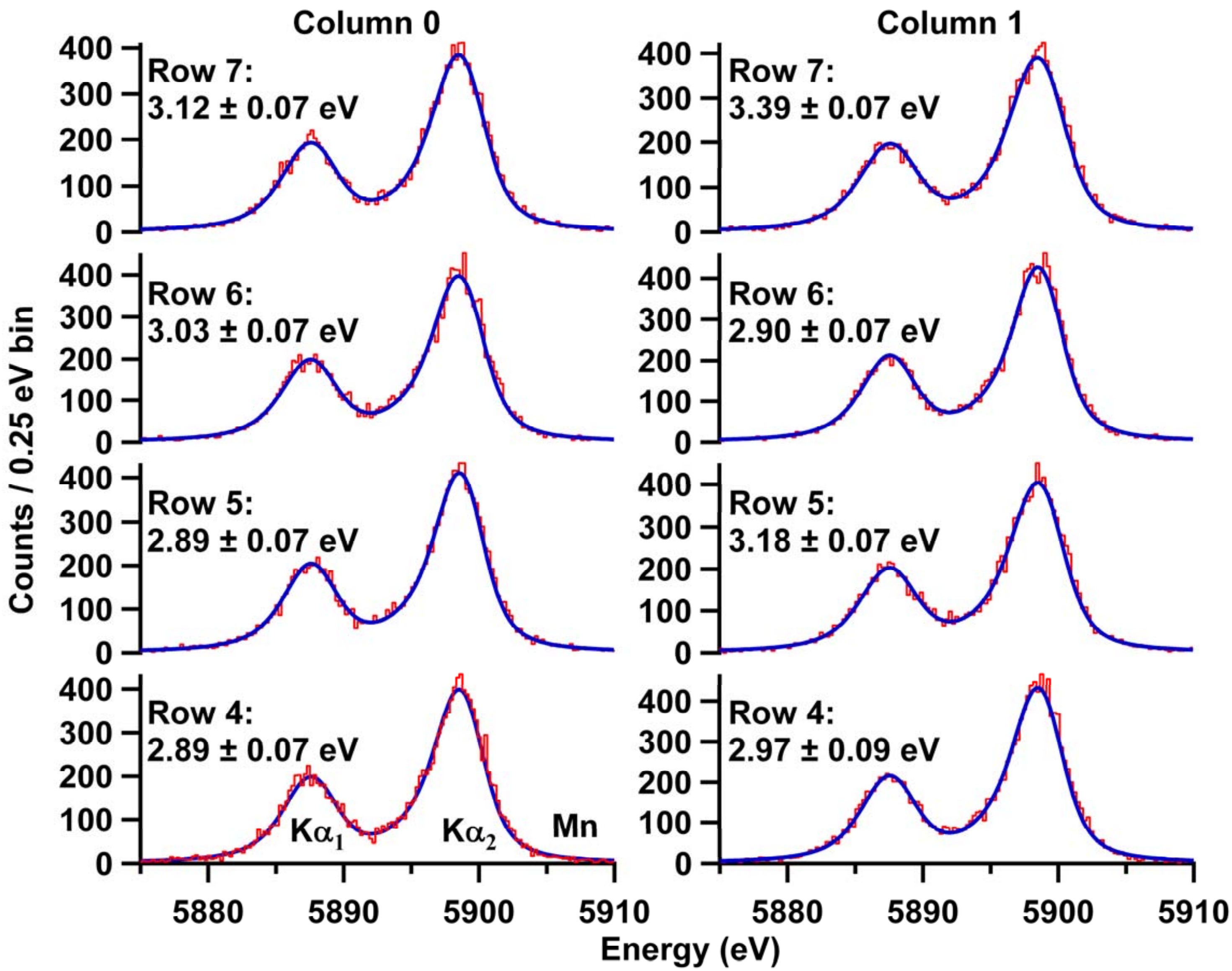




Best Energy Resolution at 97 keV, Corresponding Pileup Loss	Optimal Filter	XIA Filter
FWHM (eV) (~ 3 cps)	29.7	28.2
Pile-up Loss (~ 3 cps)	41.3%	10.7%
FWHM (eV) (~ 11 cps)	55.6	53.0
Pile-up Loss (~ 11 cps)	71.5%	39.6%

Tan et al., "High Rate Pulse Processing Algorithms for Microcalorimeters," LTD-13, AIP Conference Proceeding, vol. 1185, pp. 294-297, 2009

XIA Filter Results: TES X-ray detectors



XIA Filter Results: TES X-ray detectors

Time Division Multiplxeing	Predicted Energy Resolution (eV, FWHM)	Optimal Filter		XIA Filter	
		Average Energy Resolution (eV, FWHM)	Average Records Acceptance Rate (%)	Average Energy Resolution (eV, FWHM)	Average Events Acceptance Rate (%)
2×4	2.82	2.68 ± 0.07	93.0 ± 0.3	3.05 ± 0.18	99.33 ± 0.05
2×8	2.89	2.93 ± 0.14	92.4 ± 0.5	3.21 ± 0.19	99.41 ± 0.05
2×12	3.02	3.04 ± 0.19	91.1 ± 1.2	3.36 ± 0.15	99.13 ± 0.07

Tan et al., "Development of a Real-time Pulse Processing Algorithm for TES-based X-ray Microcalorimeters," IEEE Transactions on Applied Superconductivity, submitted for publication

Summary & Outlook

- We built prototype main processor boards and AFE daughter cards. NIST daughter card is in production. We are finalizing the design for the main processor boards and AFE daughter cards.
- Significant efforts on developing real time pulse processing algorithms for microcalorimeters. Achieved better or comparable energy resolutions that were achieved by optimal filtering, while significantly improved pulse acceptance rates.
- Project is Phase III now: strong interests in our electronics from the microcalorimeter community.
- Already received commercial orders for the main board/AFE daughter card system.