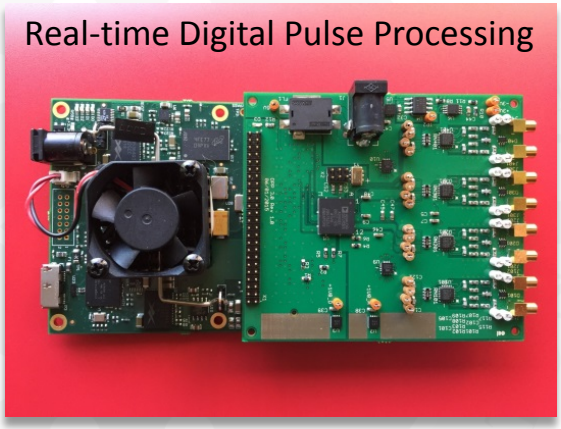
RADIOXENON DETECTION VIA BETA-GAMMA COINCIDENCE TECHNIQUE

A. Farsoni, E. Becker, L. Ranjbar,
S. Czyz, and D. Hamby

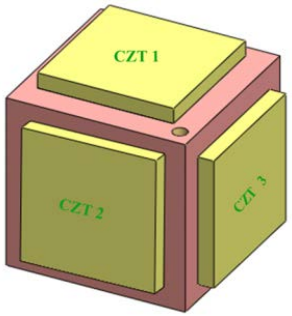
School of Nuclear Science and Engineering
Oregon State University

Research Objectives

- Design, build, and test compact radioxenon detection systems using room-temperature semiconductor detectors (CdZnTe) through beta-gamma coincidence counting



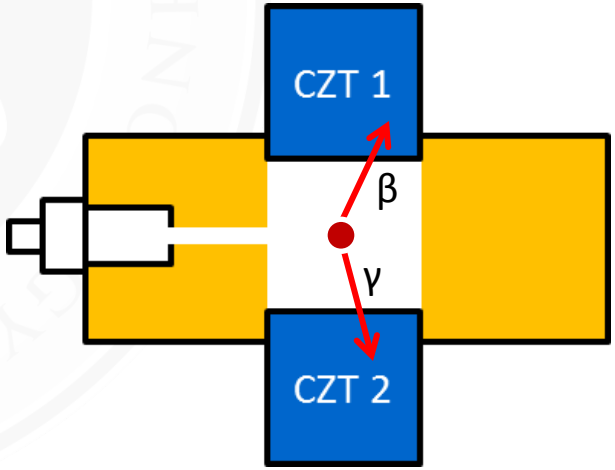
6-element CZT detector



- Advantages:
  - Better energy resolution
  - Reduced memory effect
  - Improved Minimum Detectable Concentration (MDC)
  - Reduced power, size, weight, and cost
- Several prototype detectors will be built and tested to find the best solution

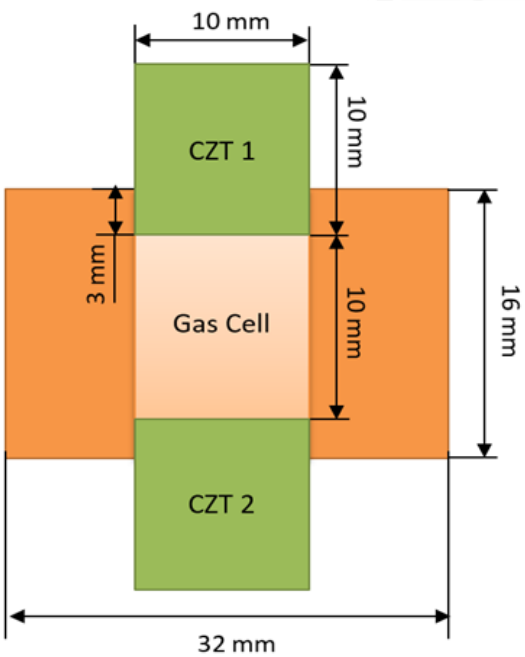
Two-element Co-planar CZT Detector (TECZT)

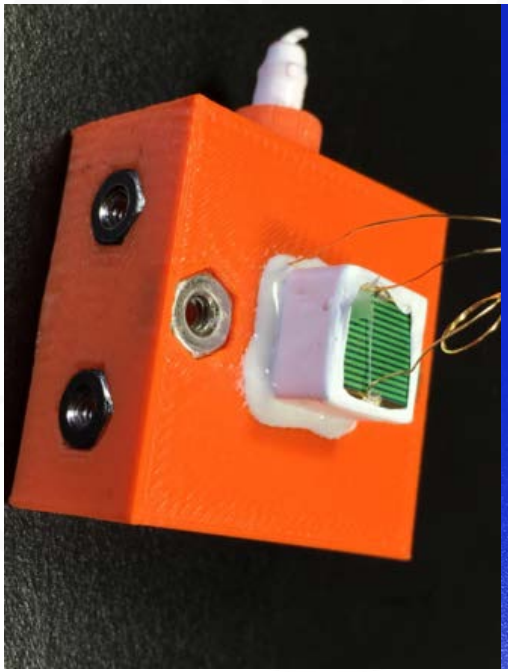
- We started with a simple design using two fact-to-face co-planar CZT detectors
- Only coincidence events between the two detectors are processed
- Coincidence probability (entering the detectors) when the source is located at the center of a cube:
  - ❑ For 2 detectors on two sides of a cubic gas cell ~ 1/18 (5.6%)
  - ❑ For 6 detectors on all sides of a cubic gas cell ~ 5/6 (83.3%)

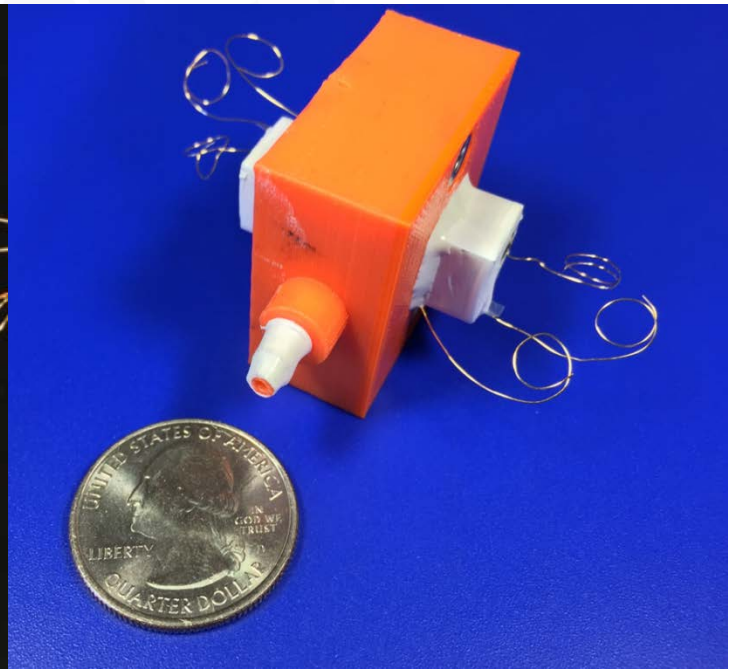


Two-element Co-planar CZT Detector (TECZT)

- Gas cell was built by 3D printing
- Two 10x10x10 mm co-planar CZT (CPCZT) crystals were air-sealed on two sides of the gas cell

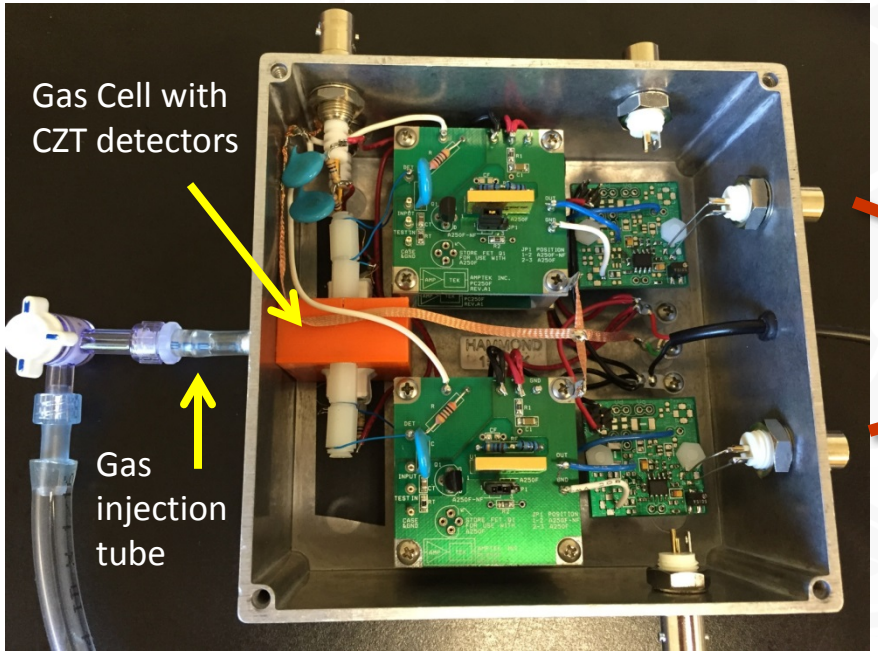






Two-element Co-planar CZT Detector (TECZT)

- CZT detectors, 4 preamplifiers and 2 subtraction PCBs were mounted in an EMI-shielded enclosure
- Detector pulses were digitized and transferred to the PC by our 2-channel, 200 MHz digital pulse processor

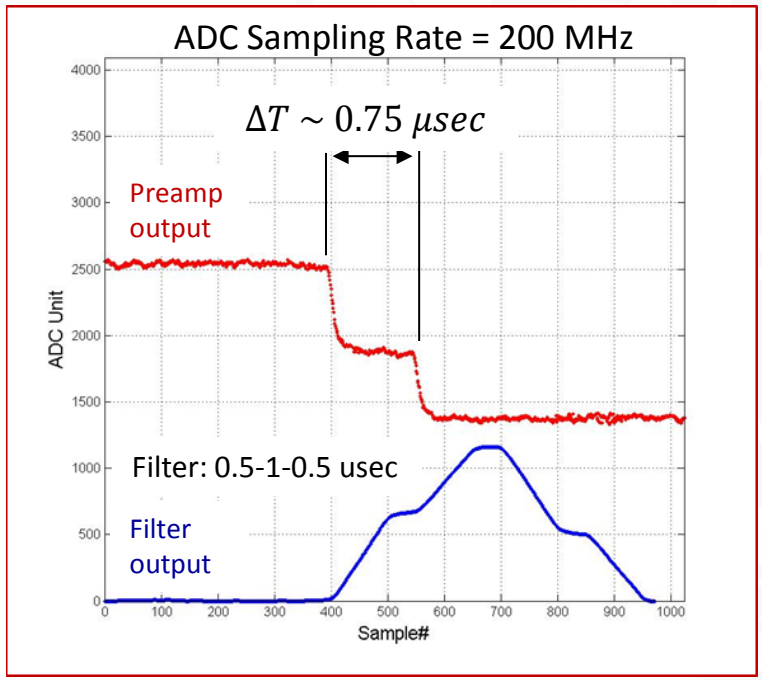


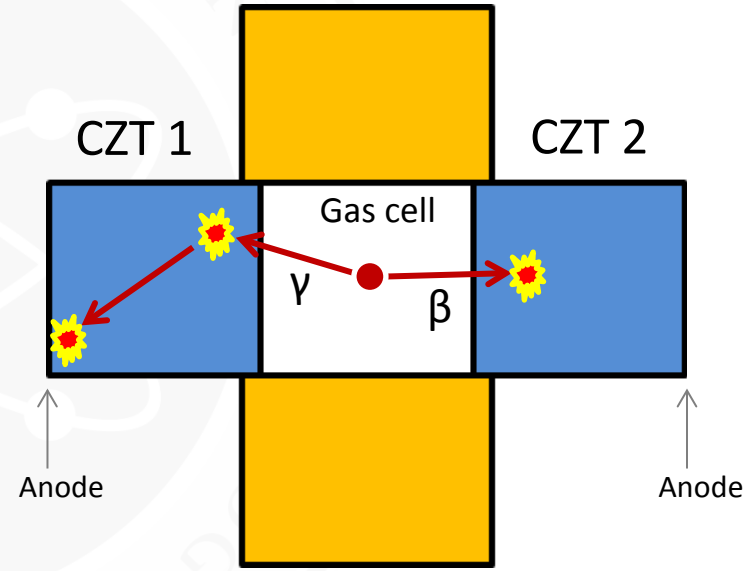
2-channel, FPGA-based 200 MHz digital pulse processor

USB
Port

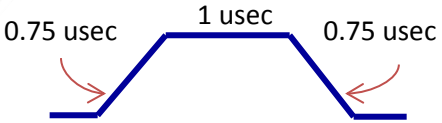
Digital Trapezoidal Pulse Shaping

- Digital trapezoidal filtering was applied to detector pulses
- Flat top duration covers both single and multi-interaction events (e.g. Compton scattering) in a single detector





Trapezoidal Filter used in this work



With V_b=1 kV, thickness=1 cm, and μ_e=1000 cm^2/VS

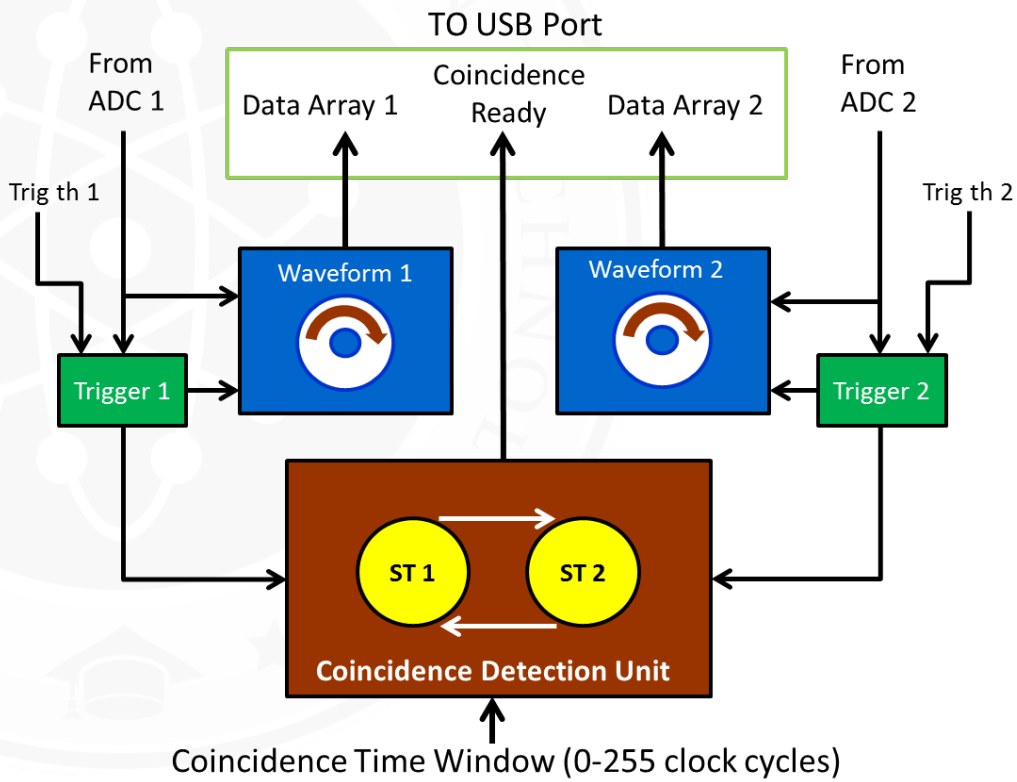
$Electron\ Drift\ Time$: $\Delta T(max) \sim 1.0\ \mu sec$

Coincidence Detection in FPGA

- Coincidence detection was performed in hardware (FPGA)
- Coincidence events are detected when the two channels are triggered within Coincidence Time Window (CTW), adjustable from 0 to 1.275 μsec

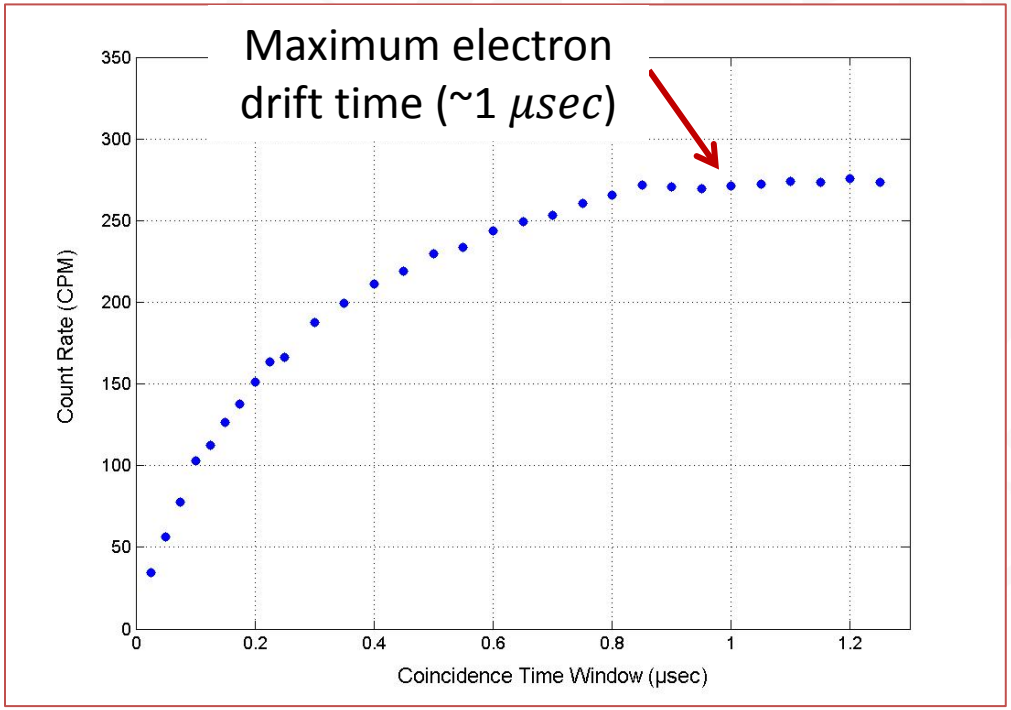
- Coincidence Detection Unit is active in Coincidence Mode

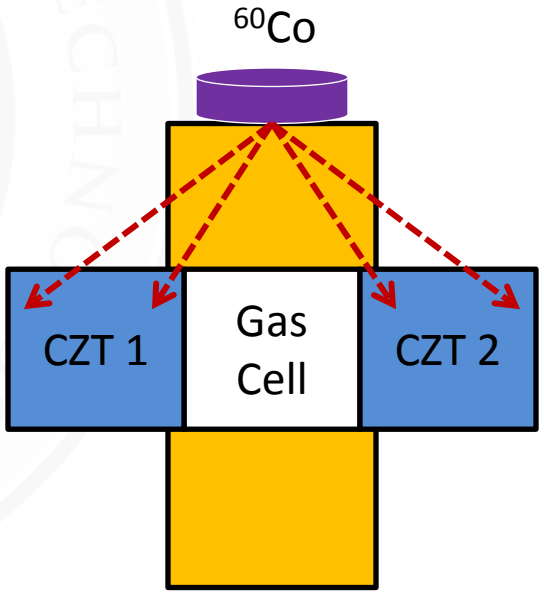
Coincidence Mode in FPGA



Coincidence Time Window

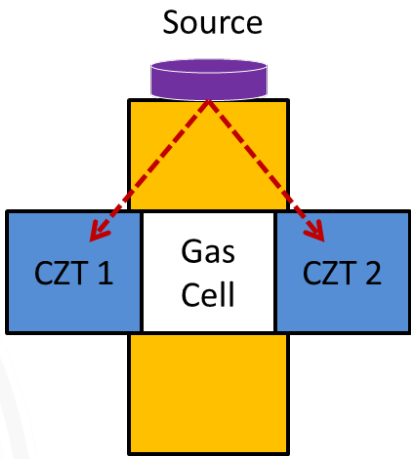
- Pulse arrival time in CPCZT is a function of interaction depth
- In coincidence mode, ^{60}Co was placed on top of gas cell and count rates were measured with different coincidence time windows
- A flat count-rate region was observed with CTW > 0.8 µsec



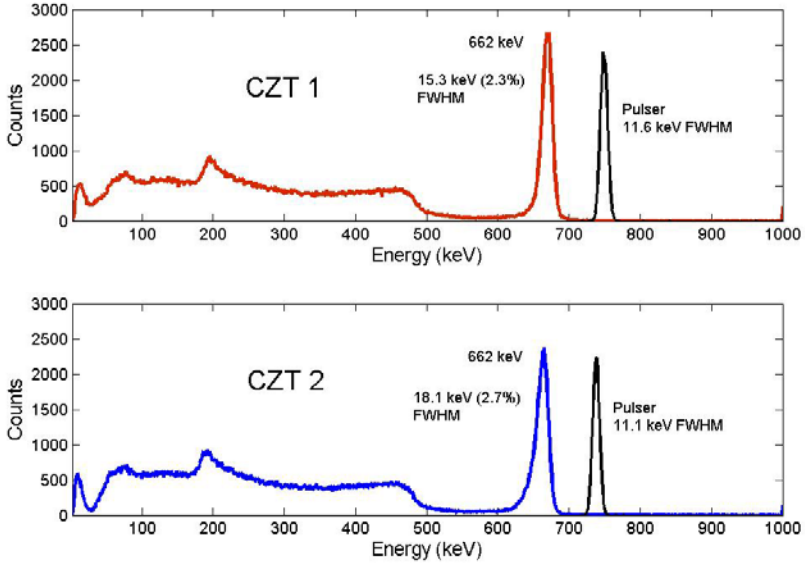


Energy spectrum from gamma sources

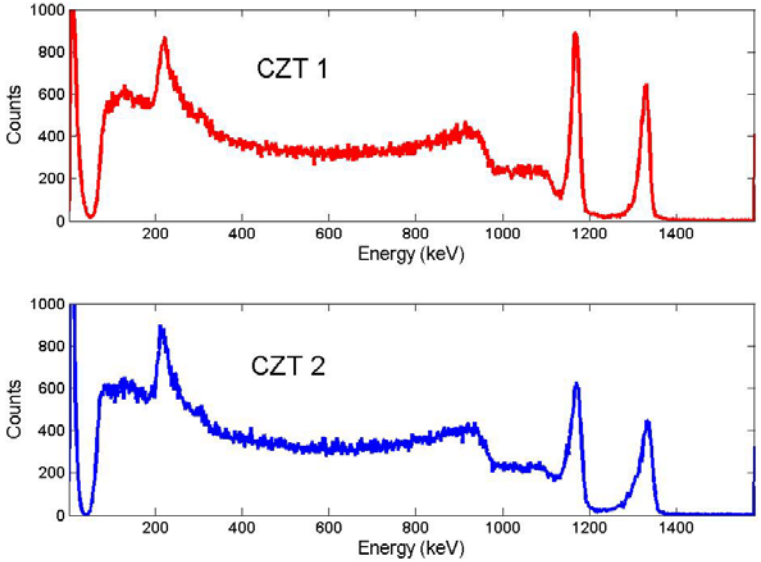
- Sources were placed on the top of the gas cell
- Better resolution is expected when the detectors are exposed from the cathode side (from inside the gas cell)



Source: ^{137}Cs

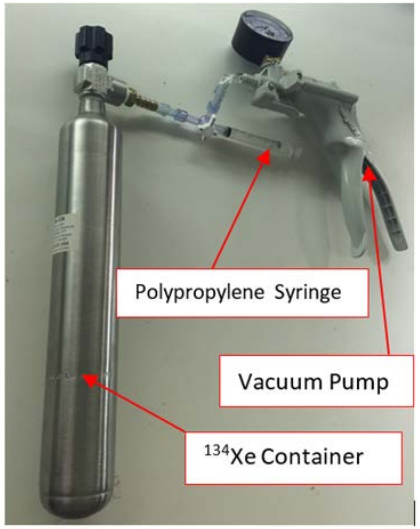


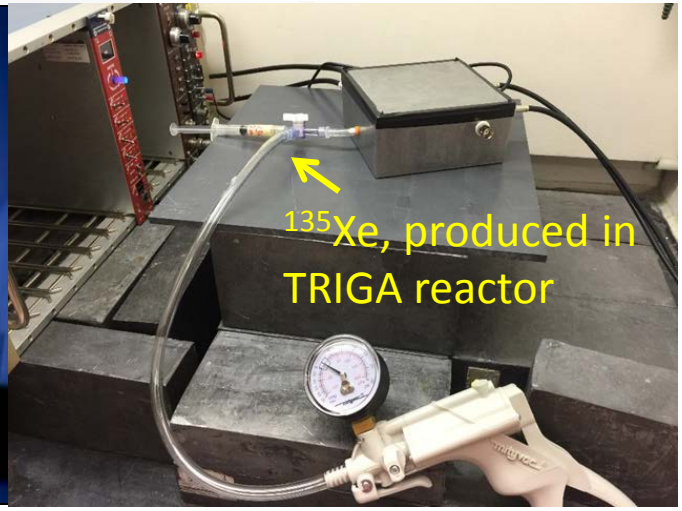
Source: ^{60}Co



Production of ^{135}Xe in TRIGA reactor

- 3 ml of stable and enriched (>99%) ^{134}Xe was irradiated in the thermal column of the TRIGA reactor for 7 hours (Ø = 7x1010 n cm^{-2} sec^{-1})
- ^{135}Xe was injected into the gas cell after 17 hrs



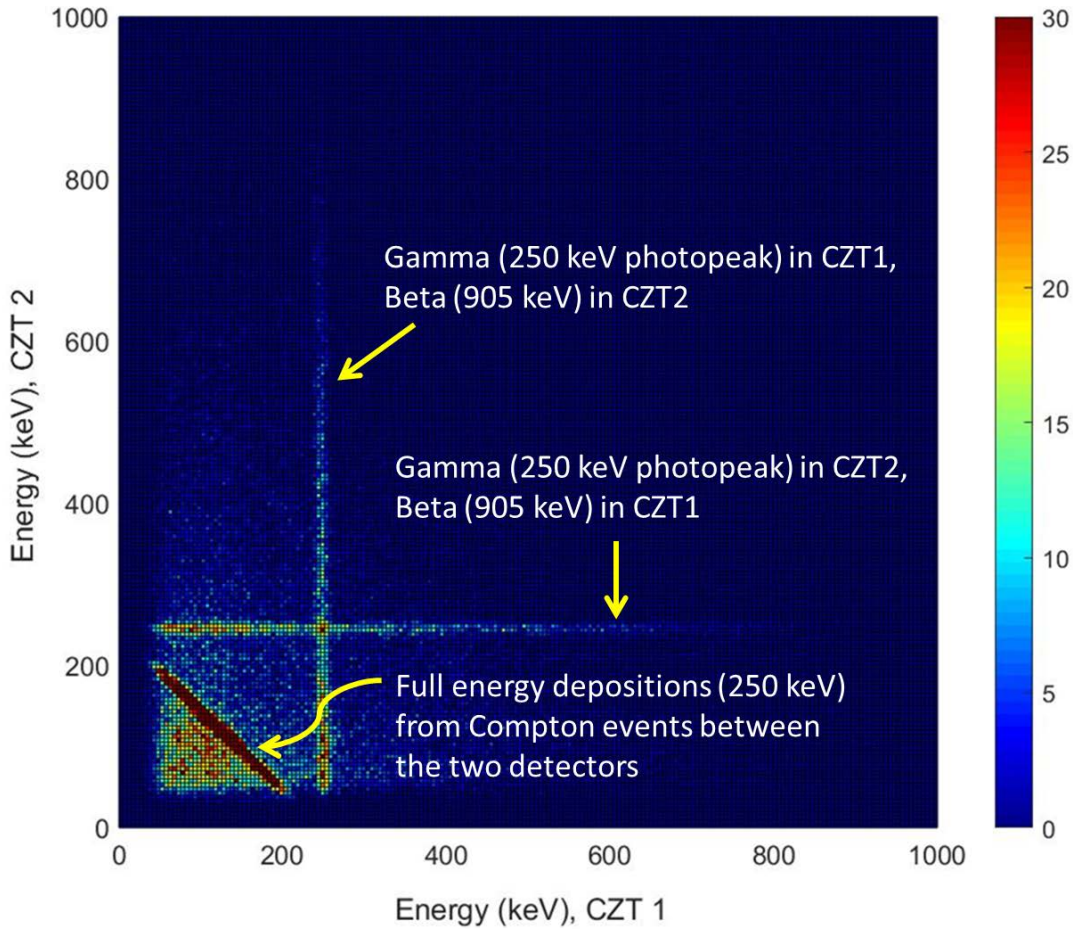


Characteristic energies for the decay of ^{131m}Xe, ^{133m}Xe, ^{133}Xe, and ^{135}Xe

Nuclide	^{131m}Xe	^{133m}Xe	^{133}Xe	^{135}Xe
Half-life	11.93 d	2.19 d	5.25 d	9.14 h
Gamma-rays (keV)	163.9	233.2	**81.0**	**250.0**
Gamma-ray abundance (%)	1.96	10.3	37.0	90.0
X-ray, K-shell (keV)	**30.**	**30.**	**31.**	31.
X-ray abundance (%)	54.1	56.3	48.9	5.2
Beta, Max Energy (keV)	-	-	**346.**	**905.**
Beta abundance (%)	-	-	99.	97.
CE, K-shell (keV)	**129.**	**199.**	**45.**	214.
CE abundance (%)	60.7	63.1	54.1	5.7

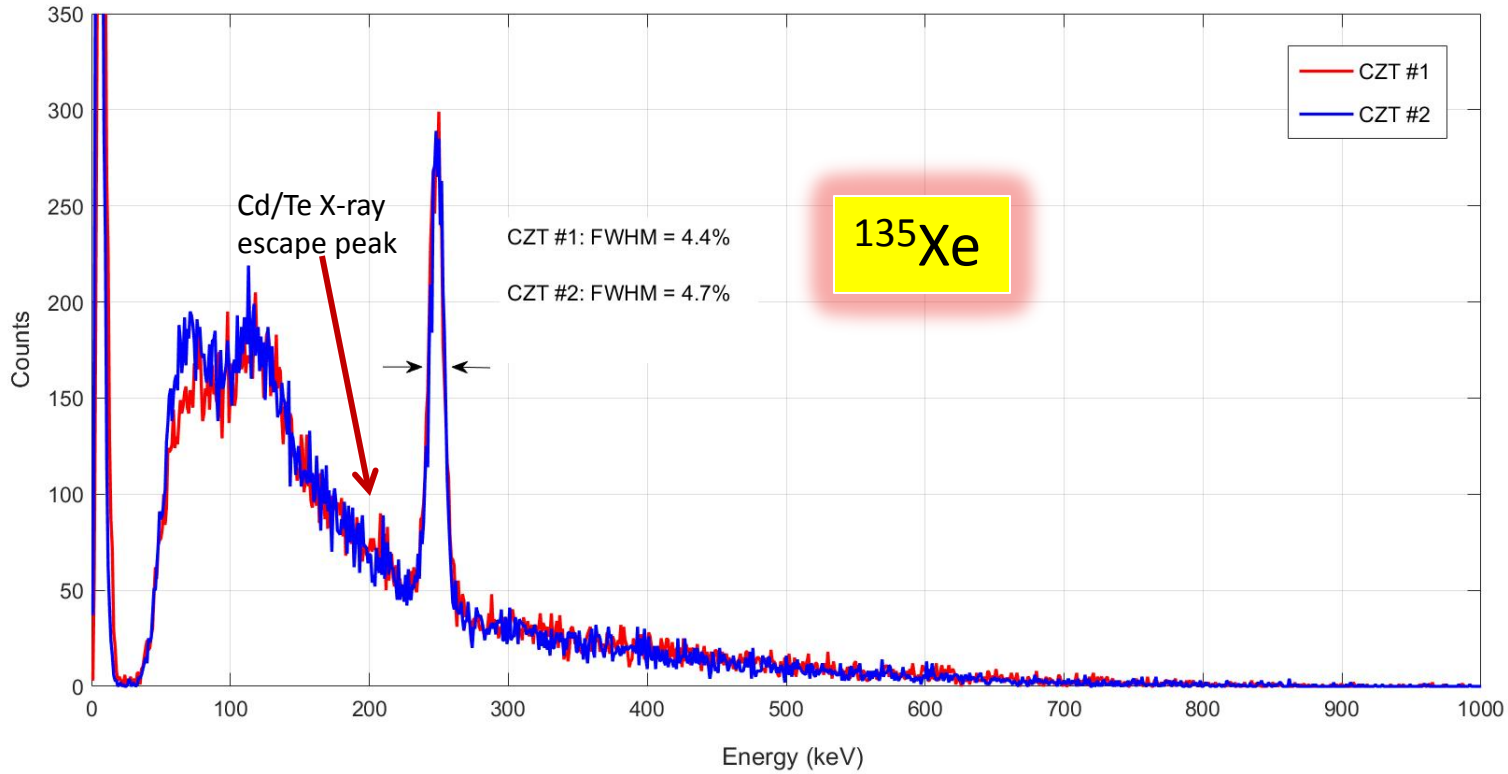
2D beta-gamma spectra from ^{135}Xe

- FPGA operation mode: **coincidence (CTW=0.75 µsec)**



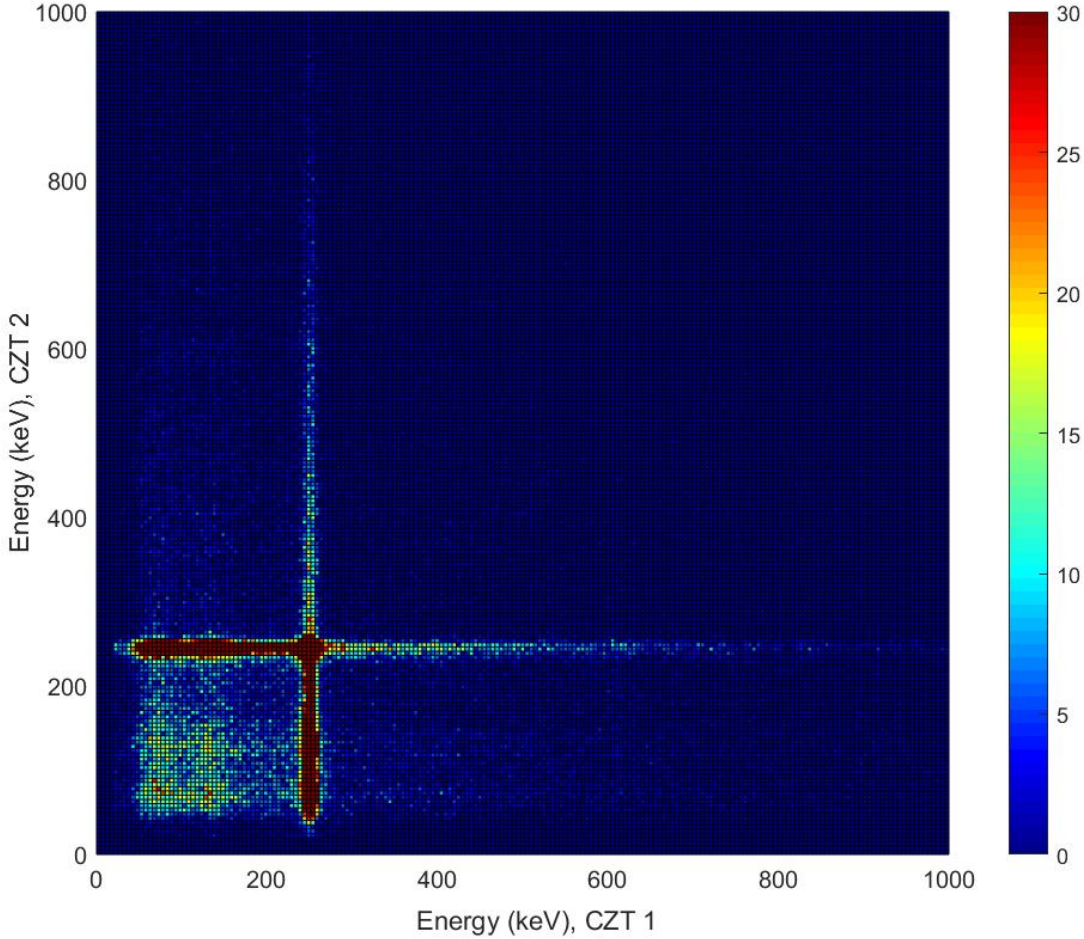
Beta-gamma coincidence spectra from ^{135}Xe

- FPGA operation mode: **coincidence (CTW=0.75 µsec)**



2D beta-gamma spectra from ^{135}Xe

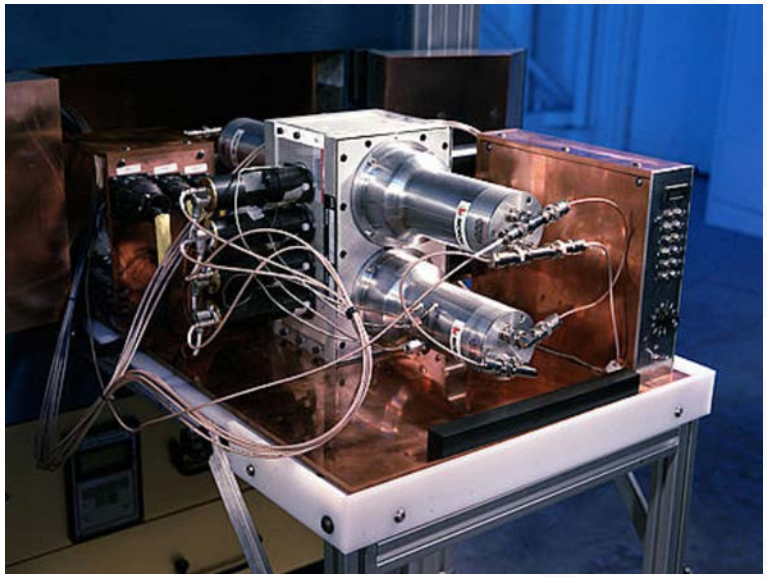
- FPGA operation mode: **free running**



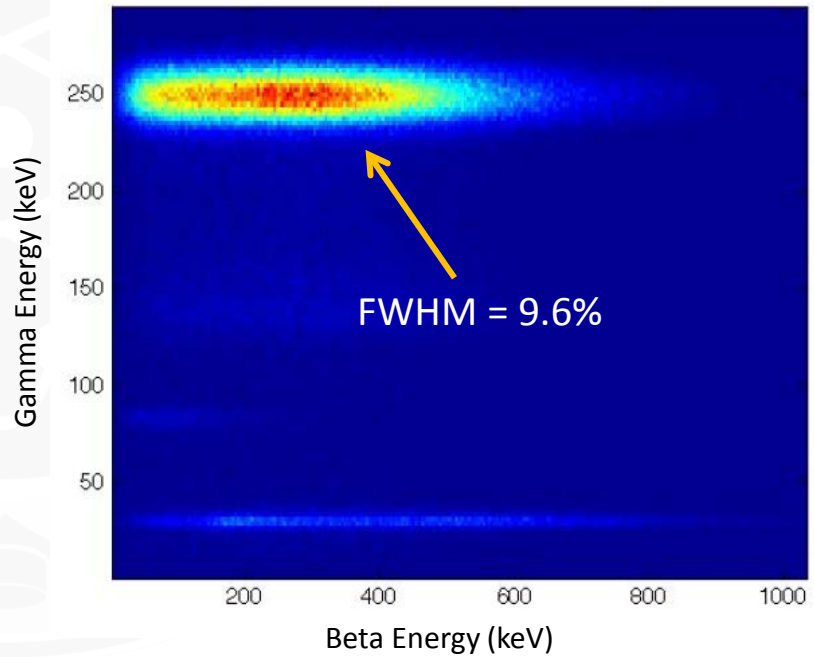
^{135}Xe in ARSA Detector

- Automated Radioxenon Sampler Analyzer developed at PNNL
- It uses NaI(Tl), plastic scintillators, and 12 PMTs to detect gamma-rays and beta particles

ARSA Detector



β-γ coincidence spectra from ^{135}Xe



TECZT and other radioxenon detectors

	Gamma Energy	TECZT (this work)	WASPD [1]	Phoswich [2]	SAUNA [3]	ARSA [4]	BGW [5]
Energy Resolution (FWHM, %)	88 keV (^{109}Cd)	11.2	31.5	25	14	NA	14
	122 keV (^{57}Co)	6	NA	24	NA	22	13
	662 keV (^{137}Cs)	2.3	13.6	8.9	7.3	12	8.7
	250 keV (^{135}Xe)	4.4	19.3	13	NA	9.6	NA
Background Rate (counts/s)	Total (all events)	0.2	1.26	3.29	7.5-12	30	5.5
	Coincidence Events	0.0036	0.02	0.06	0.03	0.1	0.025

NA: data is not available

[1] Alemayehu, B.; Farsoni, A. T.; Ranjbar, L.; Becker, E. M. "A Well-Type Phoswich Detector for Nuclear Explosion Monitoring," Journal of Radioanalytical and Nuclear Chemistry, Vol. 301, Issue 2, 323-332; 2014

[2] A. T. Farsoni, B. Alemayehu, A. Alhawsawi, E. M. Becker,"A Phoswich Detector with Compton Suppression Capability for Radioxenon Measurements," Ieee Transactions on Nuclear Science, vol. 60-1, 2013.

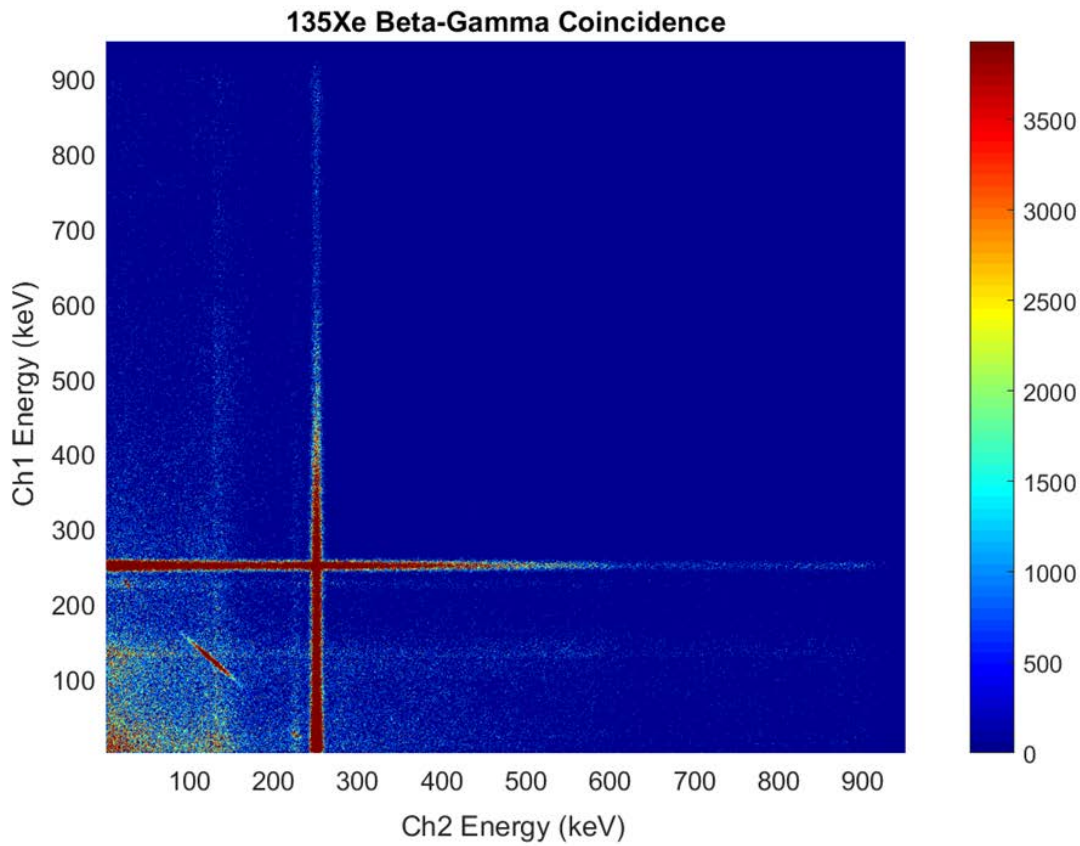
[3] A. Ringbom, T. Larson, A. Axelson, K. Elmgren, and C. Johonson, "SAUNA- a system for automatic sampling, processing and analysis of radioactive xenon," Nucl. Instr. Meth. in Phys. Res. A, vol. 508, p.542, 2003.

[4] P. L. Reeder, T. W. Bowyer, J. I. McIntyre, W. K. Pitts, A. Ringbom, and C. Johansson, "Gain calibration of coincidence spectrometer for automated radioxenon analysis," Nucl. Instr. Meth. in Phys. Res. A, vol. A521, p. 586, 2004.

[5] M. W. Cooper, J. I. McIntyre, T. W. Bowyer, A. J. Carman, J. C. Hayes, T. R. Heimbigner, C. W. Hubbard, L. Lidey, K. E. Litke, S. J. Morris, M. D. Ripplinger, R. Suarez, and R. Thompson, "Redesigned β-γ radioxenon detector," Nucl. Instr. Meth. in Phys. Res. A, vol. A579, p. 426, 2007.

MCNP coincidence simulation

- PTRAC card was used to simulate beta-gamma coincidence events



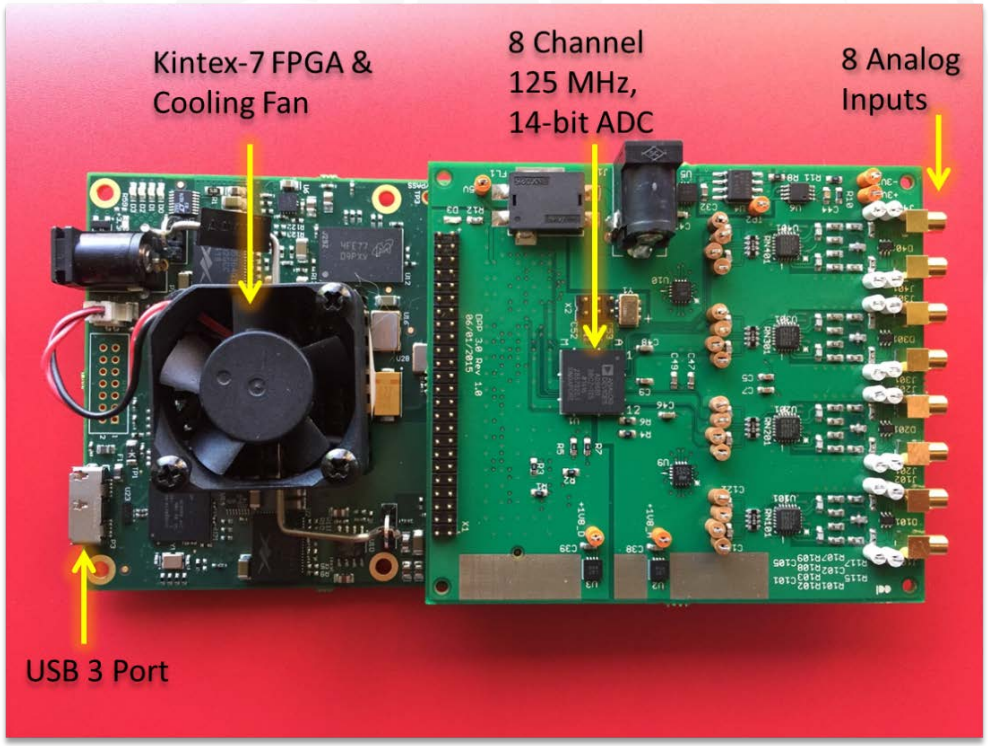
- Visit Lily Ranjbar's poster (poster #6) for more detail:

Coincidence Simulation of a Two-Channel CZT-based Radioxenon Detector

Other ongoing projects

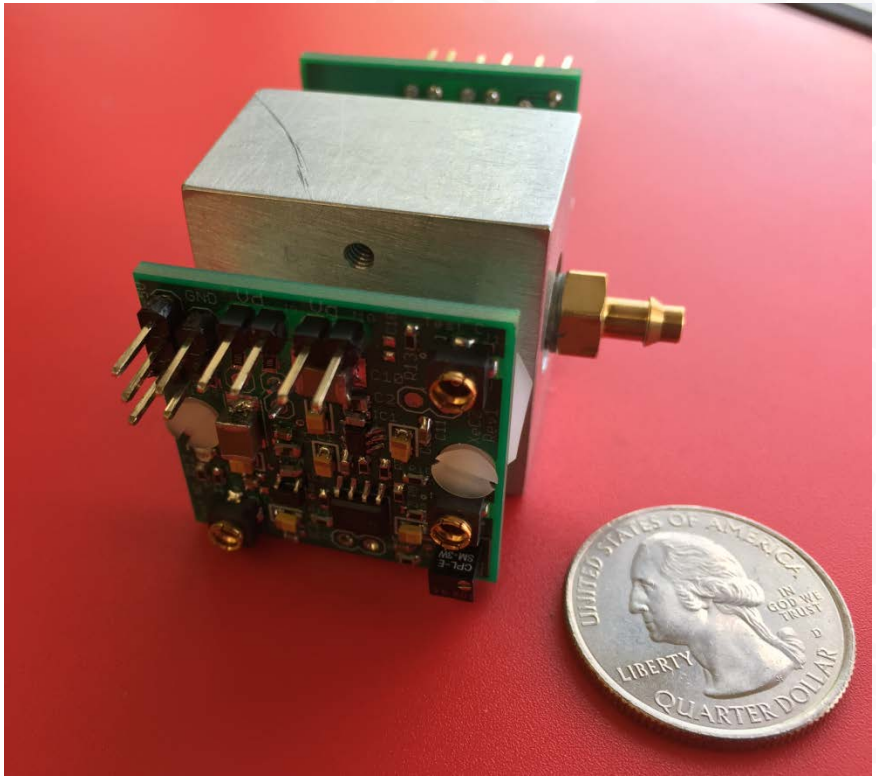
- A 8-channel FPGA-based DPP was designed and built
- To be used in our next generation detector with 6 CZT elements
- Will be tested during the 2nd year

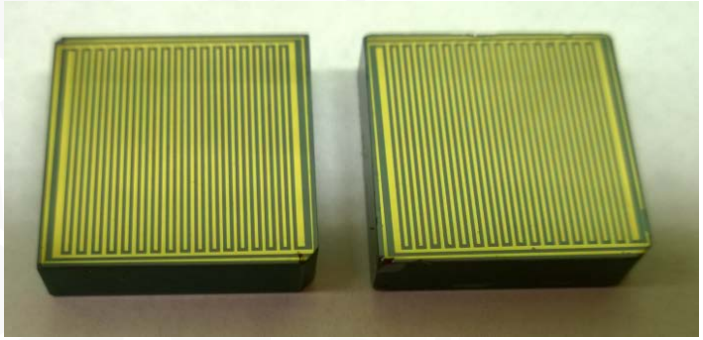
8-Channel, 14-bit, 125 MHz Digital Pulse Processor

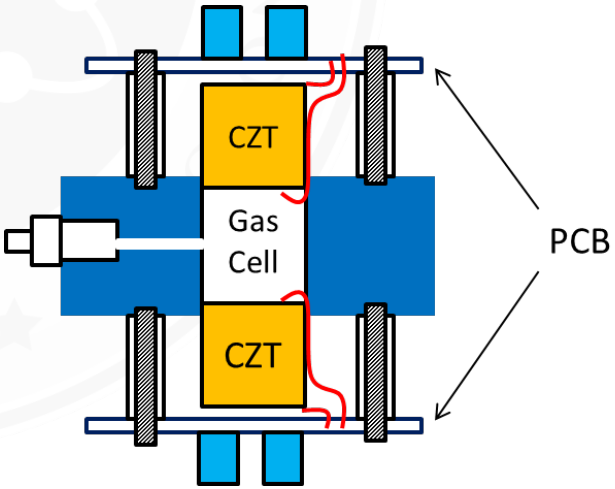


Other ongoing projects

- Depositing co-planar patterns on 20x20x5 mm CZT crystals
- Miniaturizing preamp+subraction PCB with CZT detectors in an aluminum gas cell







Future Work

- Reduce noise level to detect 30 keV X-rays from ^{131m}Xe, ^{133m}Xe, ^{133}Xe
- Test the detector with other xenon radioisotopes (^{131m}Xe, ^{133m}Xe, ^{133}Xe)
- Calculate Minimum Detectable Concentration through simulation and experiments
- Test and troubleshoot our 8-channel digital pulse processor

Conclusion

- Two-element CZT detector was designed, built, and tested by injecting ^{135}Xe into the gas cell
- FPGA firmware (two-channel, 200 MHz) was developed to identify and capture coincidence events in real time
- Preliminary measurement results show improved energy resolution compared with other radioxenon detectors such as ARSA and SAUNA
- Compact 8-channel (FPGA-based, 14 bits, 125 MHz) digital pulse processor was designed and built

Thank You!