

Development of a Radioxenon Detection System Using CdZnTe, Array of SiPMs, and a Plastic Scintillator

Steven Czyz

Farsoni, A., Ranjbar, L., Gadey, H.

School of Nuclear Science and Engineering
Oregon State University



Consortium for Verification Technology



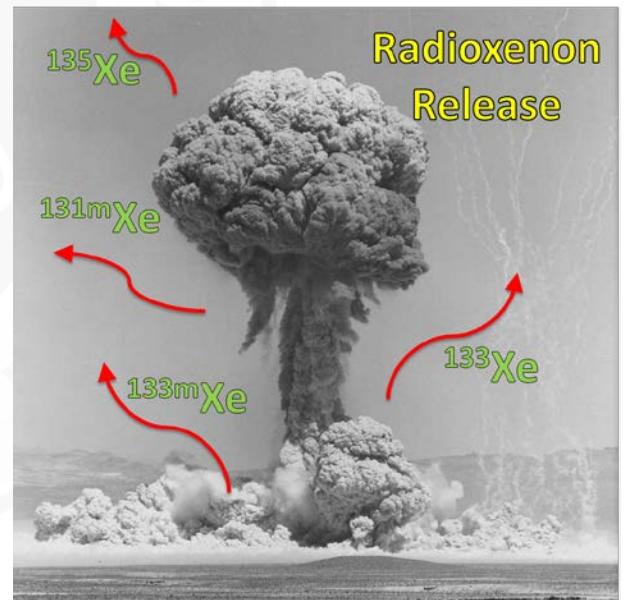
Outline

- Motivation
- Results from first prototype- TECZT
- Impetus, and a new design
- CASP: CdZnTe, Array of SiPMs, and Plastic Scintillator
- Measurement
- Conclusions and Outlook



Motivation

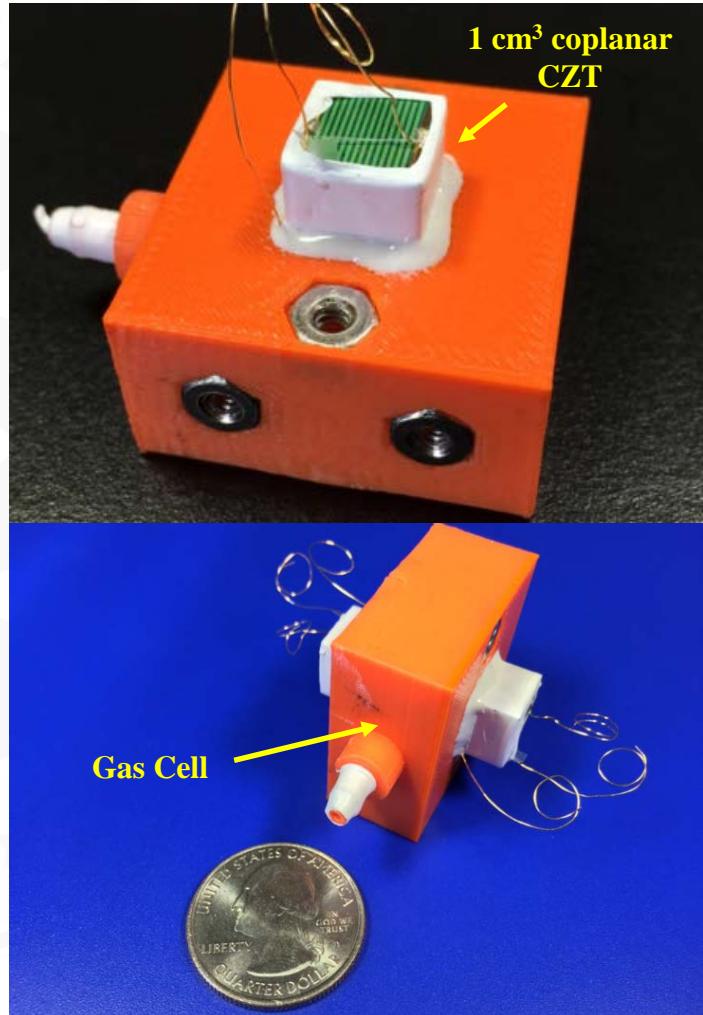
- ABCs of the IMS (International Monitoring System)
 - Atmospheric Radioxenon
 - Beta-Gamma Coincidence
 - Comprehensive Test Ban Treaty Organization (CTBTO)
- Design of detection systems
 - 4 isotopes (^{131m}Xe , ^{133}Xe , ^{133m}Xe , ^{135}Xe)
 - $< 1 \text{ mBq/m}^3$ air
- Desirable features
 - Long-term autonomous operation
 - High resolution at room temperature
 - High res = tight regions of interest (ROI)
 - Compact, low power, and low cost
 - Good background/noise rejection



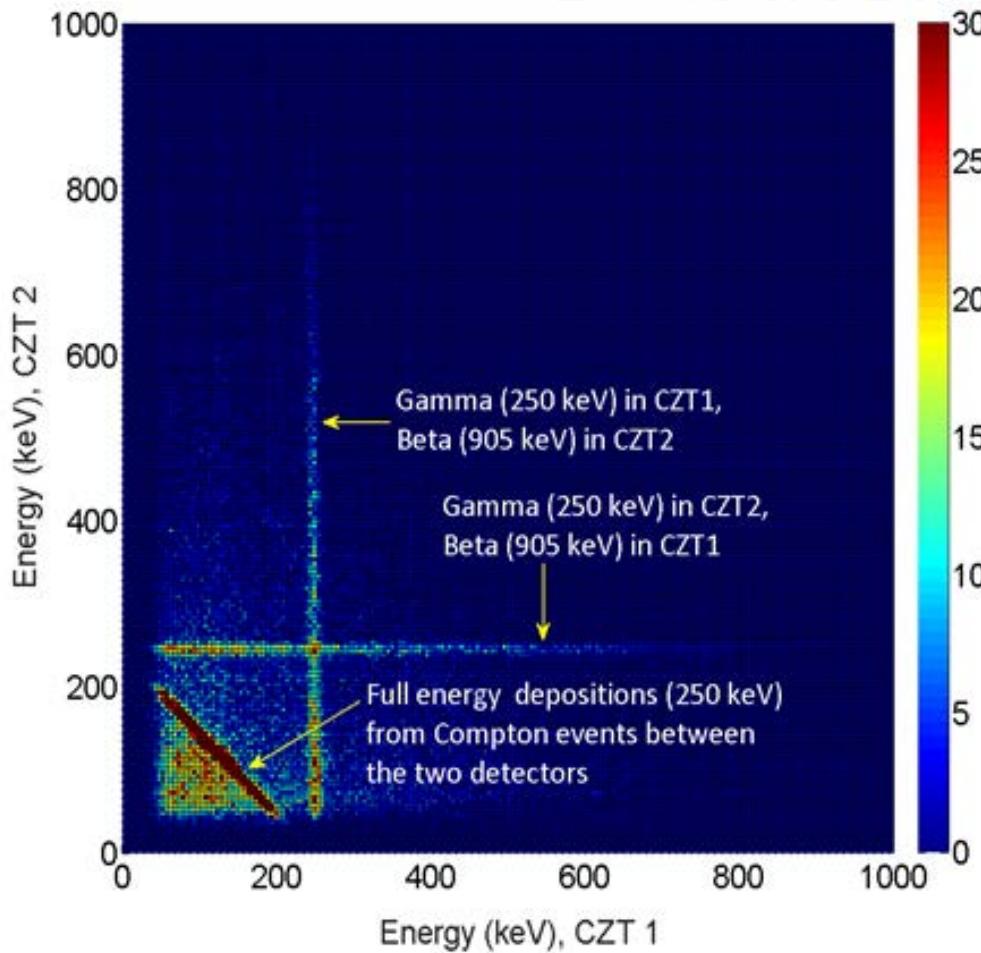
First Prototype Results- TECZT

- Two coplanar CZT surrounding gas cell
 - High resolution for tight ROIs
 - Room temperature operation
 - Simple readout electronics
 - Minimize memory effect
- Dual-channel digital pulse processor
 - FPGA coincidence discrimination for fast processing
- Results*
 - Radioxenon injection
 - Calculated MDCs

*For further detail, see “A CZT-based radioxenon detection system in support of the Comprehensive Nuclear-Test-Ban Treaty, Ranjbar, L., Farsoni, A.T. & Becker, E.M. J Radioanal Nucl Chem (2016)”



TECZT- ^{135}Xe



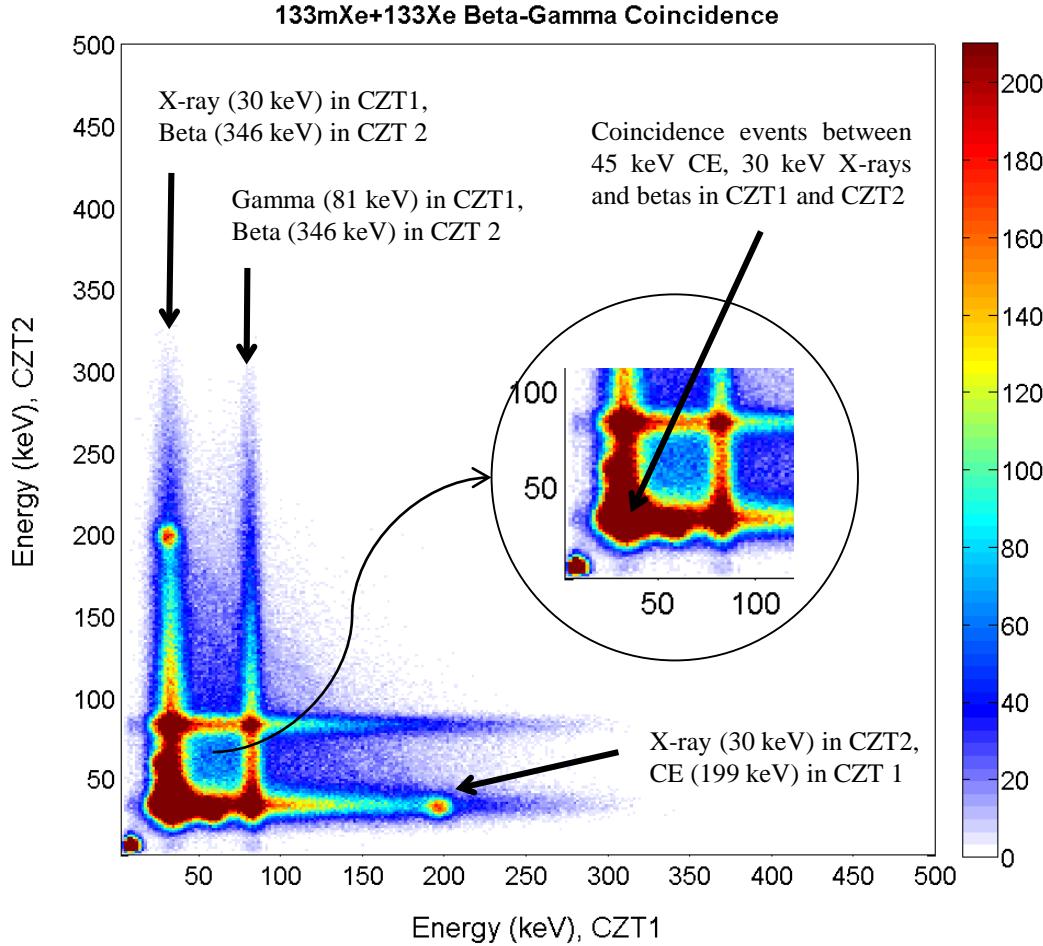
^{135}Xe Parameters	Value
Half-Life (hours)	9.14
Gamma (keV)	250
Max Beta (keV)	905



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TECZT- ^{133m}Xe

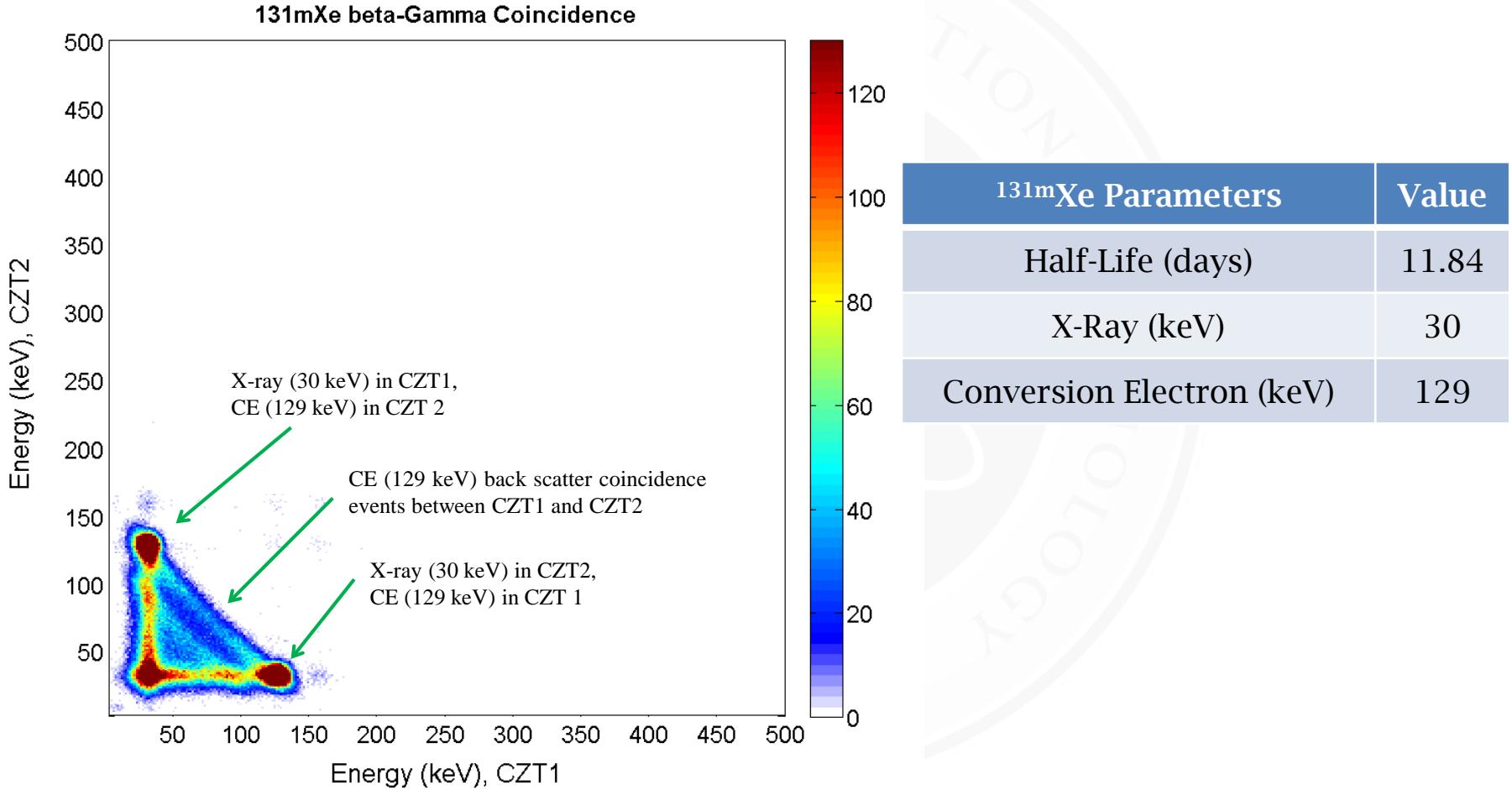


^{133}Xe Parameters	Value
Half-Life (days)	5.243
X-Ray (keV)	30
Gamma (keV)	81
Max Beta (keV)	346
Conversion Electron (keV)	45

^{133m}Xe Parameters	Value
Half-Life (days)	2.19
X-Ray (keV)	30
Conversion Electron (keV)	199



TECZT- ^{131m}Xe



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TECZT- Resolutions

	Gamma Energy (keV)	TECZT (this work)	WASPD [1]	Phoswich [1]	SAUNA [2][3]	ARSA [2][4]	BGW [5][6]
Energy Resolution (FWHM, %)	30 (¹³³ Xe)	48.2	47.7	46	23-30	32	18
	81 (¹³³ Xe)	12.5	27.6	24	13	25	13
	250 (¹³⁵ Xe)	4.4	19.3	13	N/A	9.6	N/A
	662 (¹³⁷ Cs)	2.1	13.6	8.9	7.3	12	8.7
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

[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] J.-P. Fontaine, F. Pointurier, X. Blanchard, and T. Taffary, "Atmospheric xenon radioactive isotope monitoring," J. Environ. Radioact., vol. 72, no. 1-2, pp. 129-135, Jan. 2004.

[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. . Reeder, T. . Bowyer, J. . McIntyre, W. . Pitts, A. Ringbom, and C. Johansson, "Gain calibration of a β/γ coincidence spectrometer for automated radioxenon analysis," Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip., vol. 521, no. 2-3, pp. 586-599, Apr. 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.

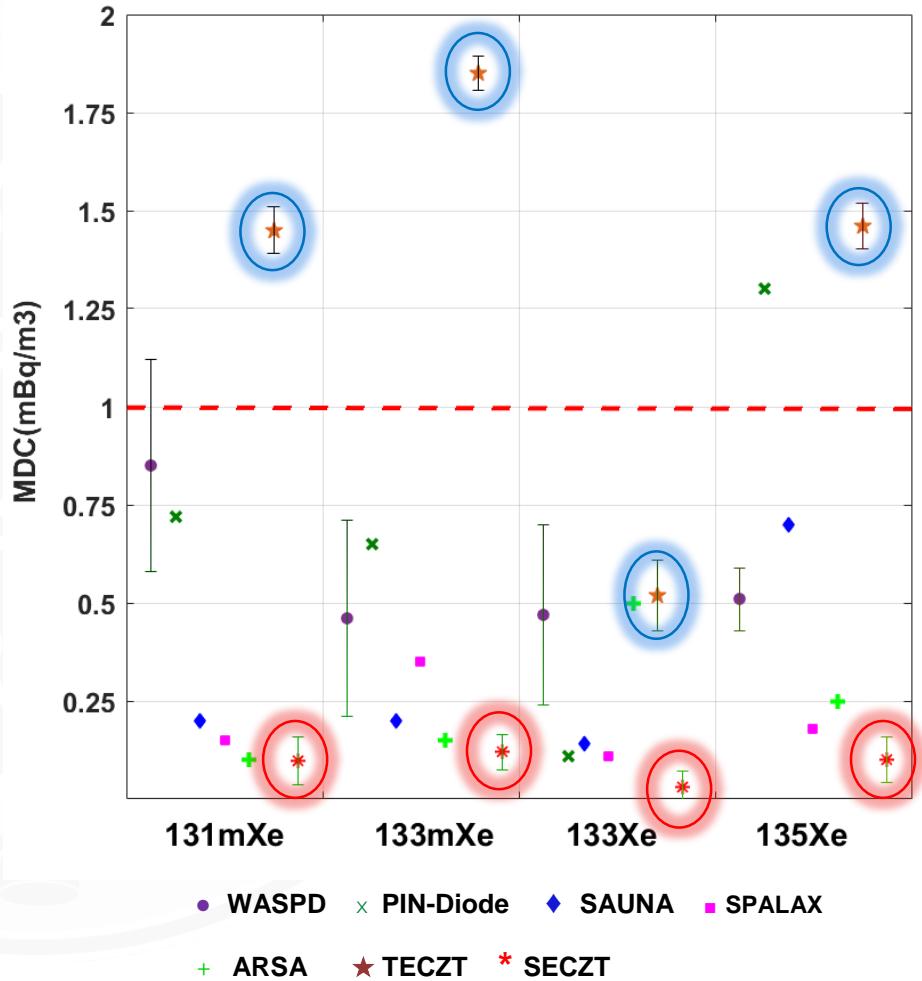
[6] J. I. McIntyre, K. H. Abel, T. W. Bowyer, J. C. Hayes, T. R. Heimbigner, M. E. Panisko, P. L. Reeder, and R. C. Thompson, "Measurements of ambient radioxenon levels using the automated radioxenon sampler/analyizer (ARSA)," J. Radioanal. Nucl. Chem., vol. 248, no. 3, pp. 629-635, 2001.



TECZT- MDCs

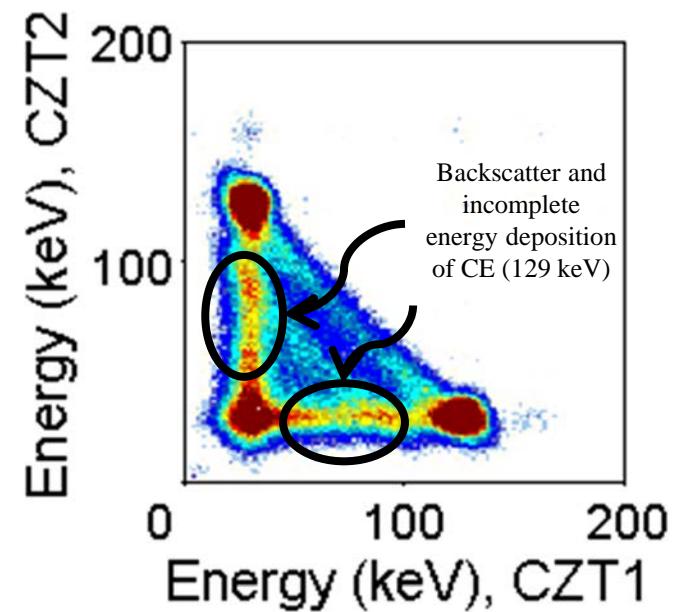
- Optimistic
 - Single isotope
 - Does not account for ROI overlap

Isotope	B- γ coincidence ROI	MDC (mBq/m ³)
^{131m} Xe	30 keV X-rays and 129 keV CE	1.45±0.06
^{133m} Xe	30 keV X-rays and 199 keV CE	1.85±0.04
¹³³ Xe	81 keV gamma and 346 beta	1.26±0.09
	30 keV gamma and 346 beta	0.57±0.09
¹³⁵ Xe	250 keV gamma and 905 keV beta	1.47±0.05



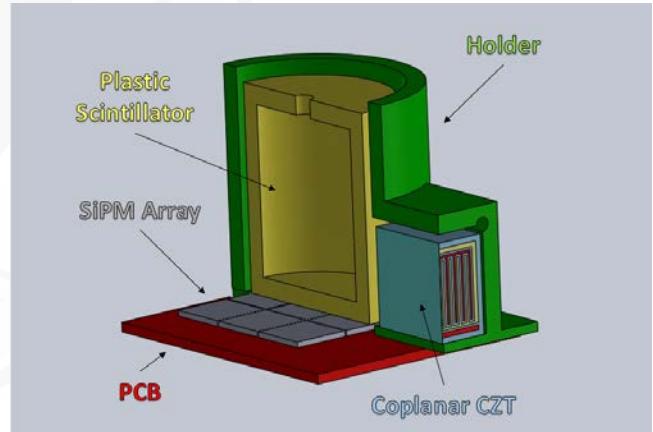
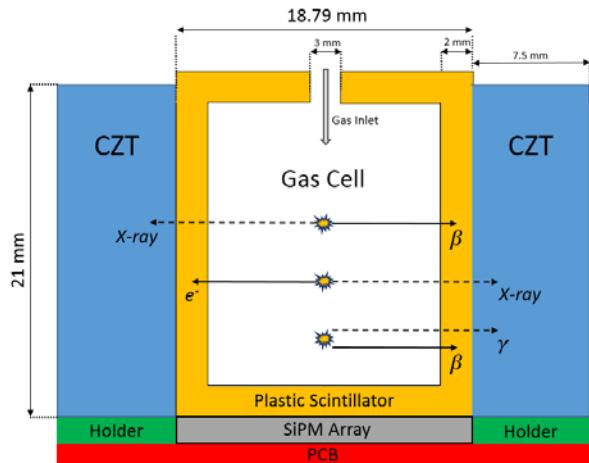
TECZT- Closing Comments, and Impetus

- Proof of concept- CZT promising material for beta-gamma coincidence radioxenon detection
- Low background count rates
- Mixed results for MDC
 - Direct improvements possible
 - Larger gas cell, larger CZT crystals
 - Six elements (SECZT)
- Shortcomings
 - Conversion electron backscatter
 - High Z
 - Interference with other ROIs
 - Worse MDCs

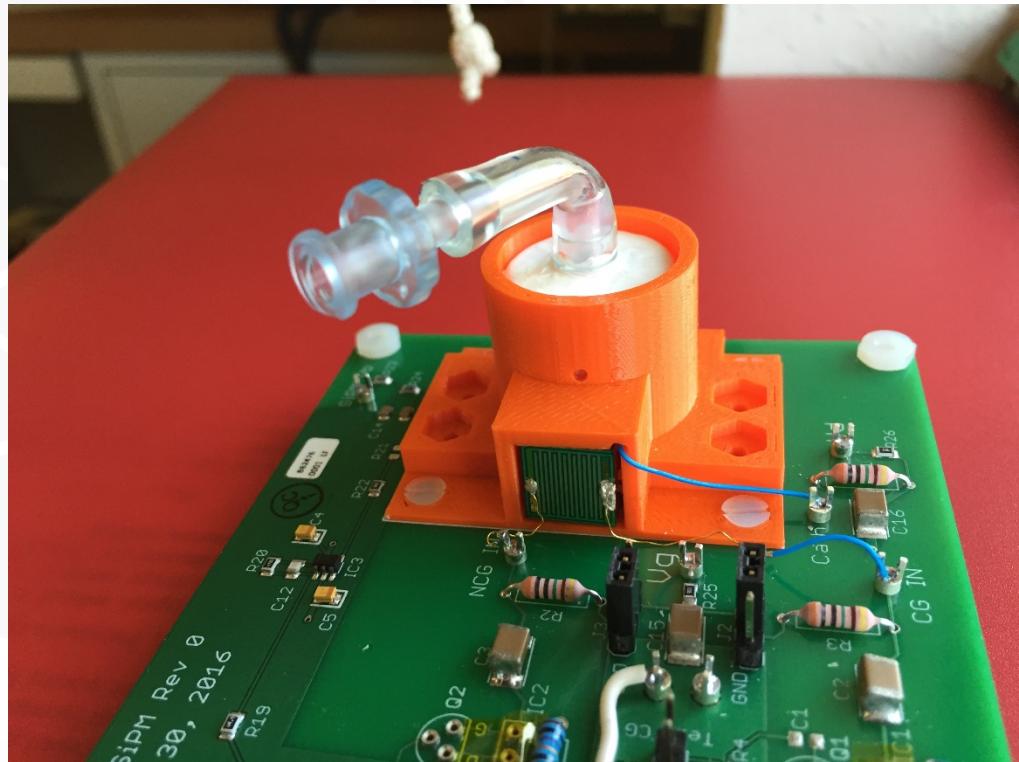
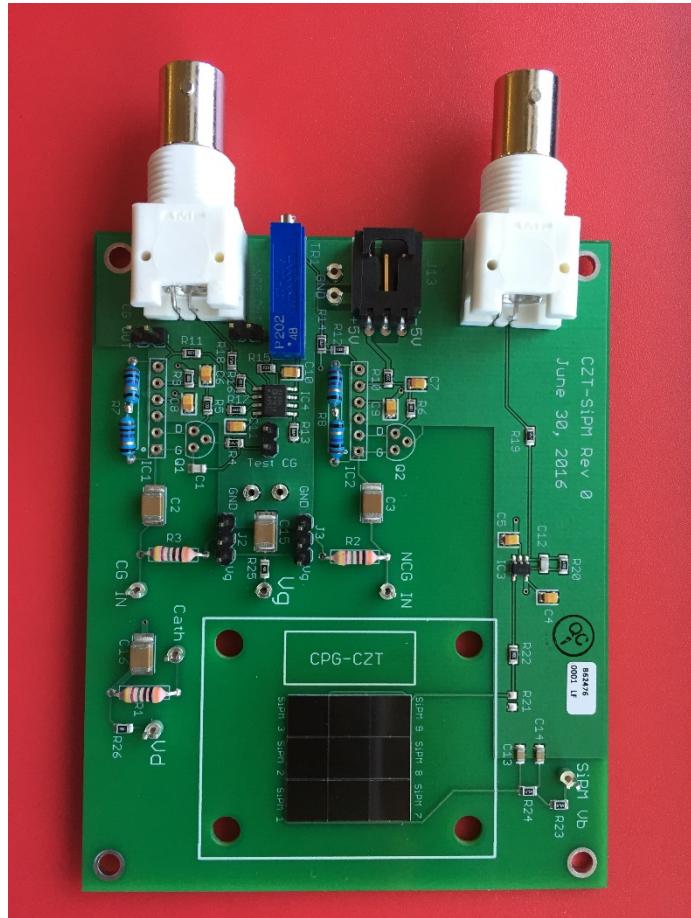


Second Prototype- What Do We Want?

- Mitigation of CE backscatter
 - Plastic scintillator gas cell
 - Low Z
 - Near 4π solid angle for electrons
 - Light collection by array of SiPMs
 - First time for β - γ radioxenon applications
- Tight ROIs
 - Adjacent coplanar CZT
 - High resolution photopeaks
- 30 keV detection
 - PCB mounted electronics
 - Low noise



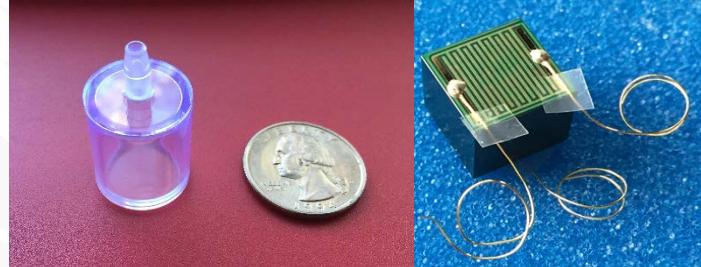
A New Design- CASP



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Materials

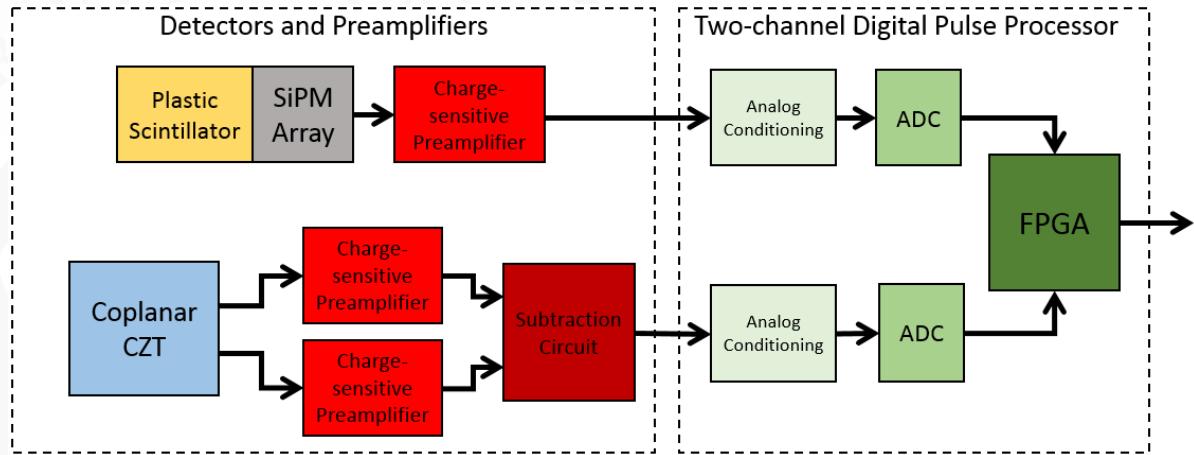
- CZT (Redlen, Coplanar)
 - Simple readout electronics
 - High resolution
 - High Z
 - Room temperature operation
- 3x3 Array of SiPMs (SensL, J-Series, 6x6 mm²)
 - High pixel density
 - Low noise
 - Small size
 - Cost
- Plastic Scintillator (Eljen, EJ-212)
 - Emission spectrum
 - Easily shaped
 - High electron intrinsic efficiency
 - Low photon intrinsic efficiency
- PCB (In-House Design)
 - Independent dual-channel readout
 - Low noise
 - Compact



<u>Dimensions (mm)</u>		
Plastic Scintillator	Height	22
	Diameter	18.79
	Wall Thickness	2
SiPM Array (3 x 3)	Length	18
	Width	18
CZT	Height	10
	Length	10
	Width	10

Electronics and Readout

- High speed coincidence discrimination conducted in FPGA
- MATLAB user interface
 - Easy adjustments of FPGA parameters
 - Real-time pulse display and energy spectra



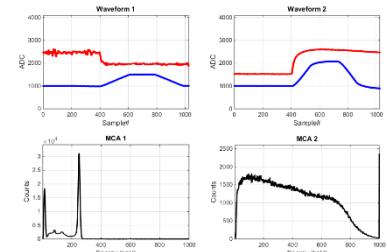
Irradiation



Injection and Detection



Dual channel digital pulse processor, with FPGA



MATLAB User Interface

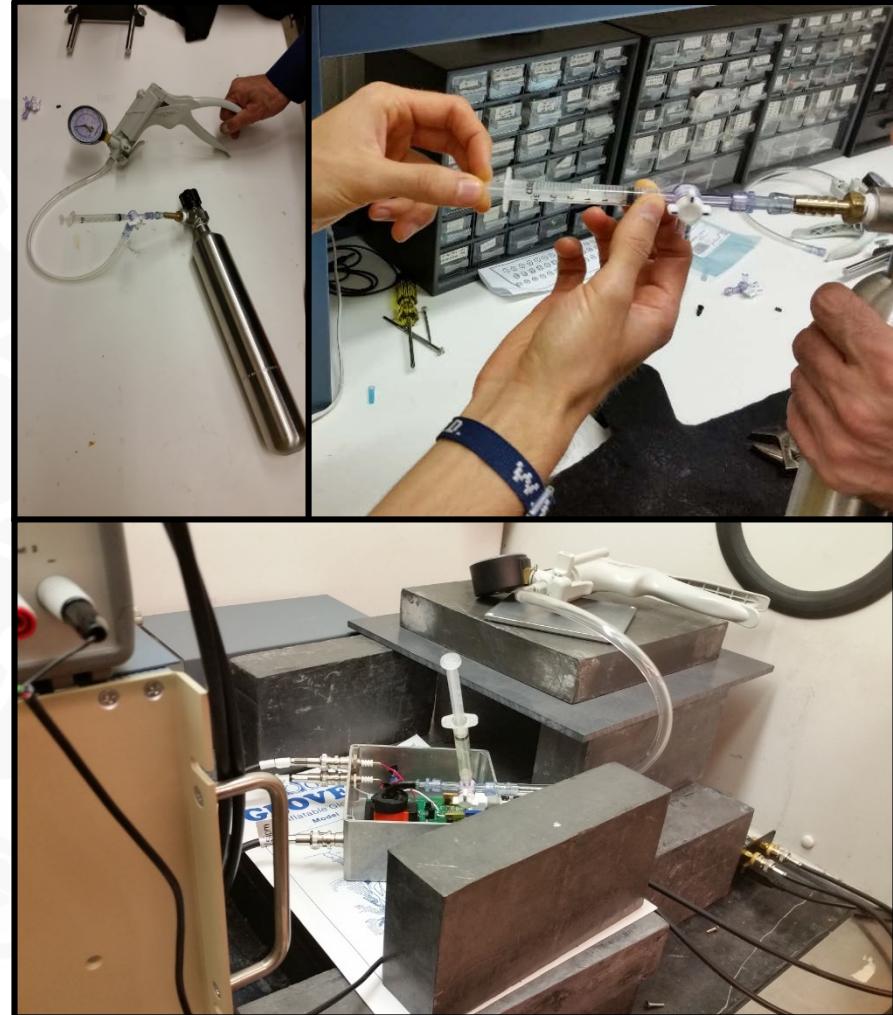
Experimental Setup- System

- Scintillator prep
 - Wrapped in Teflon for enhanced light collection
 - Tube painted black and connected to top of gas cell for radioxenon sample injection
- Complete coverage light sealing tape
 - SiPM single photon sensitivity
- Grounded metal box
 - Shielding against background, ambient light, and electrical interference
 - External access to power sources, trimmer, and signal readouts



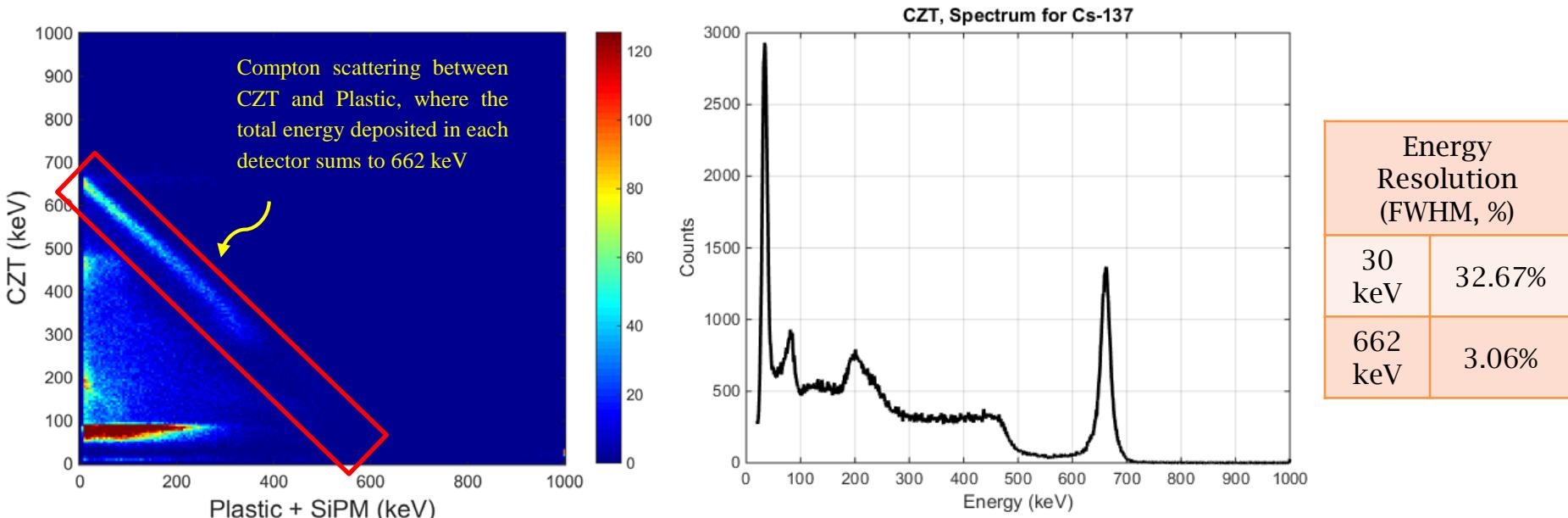
Experimental Setup- Radioxenon

- 3 mL samples each of ^{130}Xe , ^{132}Xe , ^{134}Xe
- Syringe and vacuum pump
- Irradiated in OSU TRIGA reactor thermal column
 - Neutron Flux- $2.51 \times 10^{11} \text{ cm}^{-2}\text{s}^{-1}$
 - ^{130}Xe - 15 hours
 - ^{132}Xe - 15 hours
 - ^{134}Xe - 8 hours
- Samples allowed to decay for at least 12 hours
 - Pileup
 - Impurities



Calibration and Results- ^{137}Cs

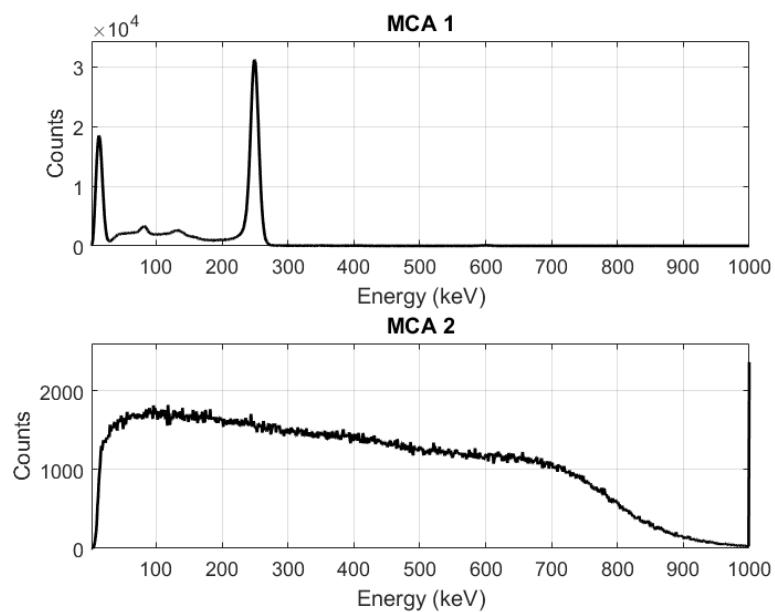
- Requirement of energy calibration* for both detectors
 - Calibrate CZT to free running spectrum of ^{137}Cs using known photopeak energies
 - Calibrate plastic via coincidence from Compton scatter between CZT and Plastic



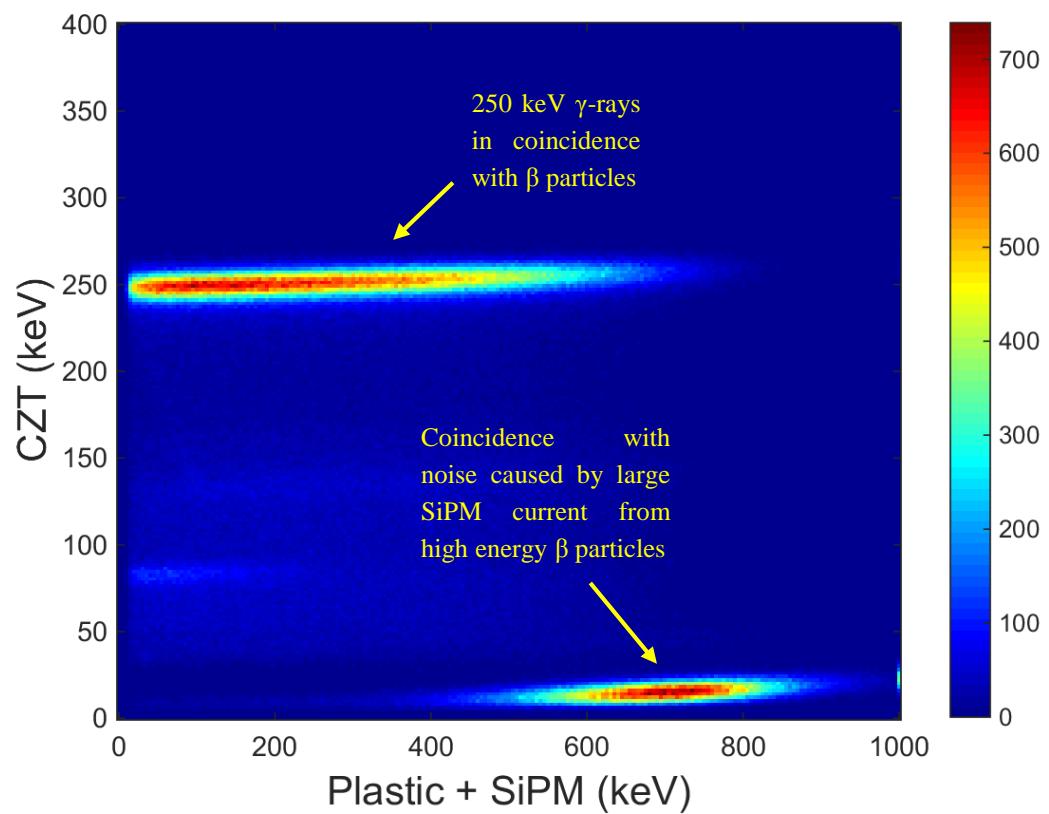
*Conducted post-radioxenon experiments due to parameter optimization

Results- ^{135}Xe

Parameters	^{135}Xe
Half-Life (hours)	9.14
Gamma (keV)	250
Max Beta (keV)	905

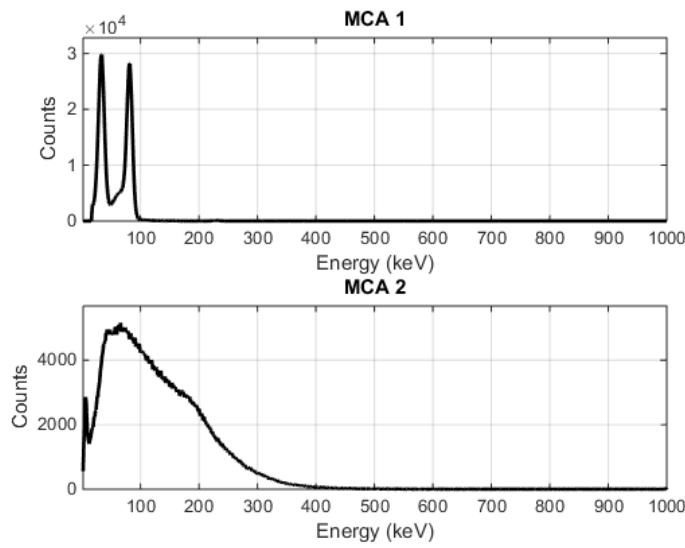


Energy Resolution (FWHM, %)	
250 keV	5.65%

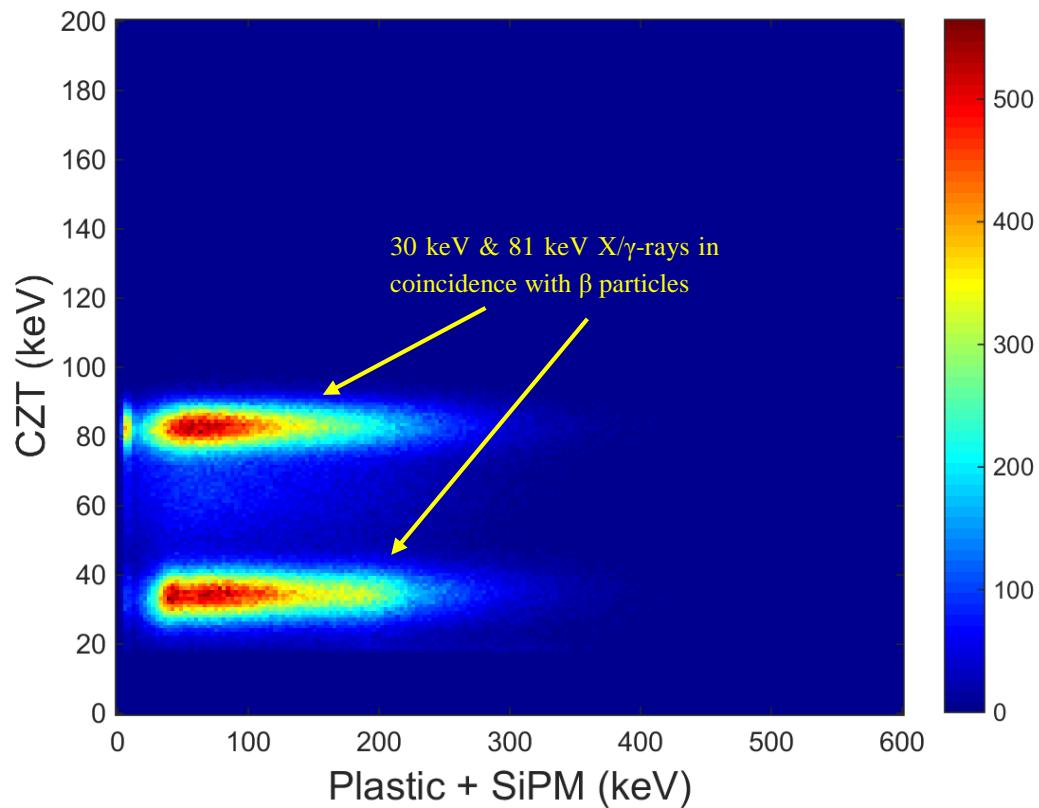


Results- $^{133}/^{133m}\text{Xe}$

Parameters	^{133}Xe	^{133m}Xe
Half-Life (days)	5.243	2.19
X-Ray (keV)	30	30
Gamma (keV)	81	-
Max Beta (keV)	346	-
Conversion Electron (keV)	45	199



Energy Resolution (FWHM, %)	
30 keV	33.39%
81 keV	12.36%



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Conclusions and Outlook

- New prototype detection system utilizing coplanar CZT, Array of SiPMs, and a Plastic scintillator has been developed
 - Testing of ^{135}Xe , $^{133}/^{133\text{m}}\text{Xe}$ have been conducted
 - Significant improvement in resolution of 30 keV compared to TECZT
 - Strong memory effect observed
- Second round of measurements to be conducted for analysis of all radioxenon isotopes, as well as background
 - Different power supply
 - Fully optimized parameters
 - MDC calculation

	Gamma Energy (keV)	CASP	TECZT	WASPD [1]	Phoswich [1]	SAUNA [2][3]	ARSA [2][4]	BGW [5][6]
Energy Resolution (FWHM, %)	30 (^{133}Xe)	33.4	48.2	47.7	46	23-30	32	18
	81 (^{133}Xe)	12.4	12.5	27.6	24	13	25	13
	250 (^{135}Xe)	5.7	4.4	19.3	13	N/A	9.6	N/A
	662 (^{137}Cs)	3.1	2.1	13.6	8.9	7.3	12	8.7



Thank You!

Questions?

This work was funded in-part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534



EXTRA SLIDES- Initial Testing

- Several sets of measurements necessary
 - ^{137}Cs
 - ^{135}Xe
 - $^{133}/^{133m}\text{Xe}$
- Initial round of measurements required to determine appropriate parameter settings
 - Voltages
 - Trimmer settings
 - Coincidence timing window
 - Filter parameters
 - Gain and offset

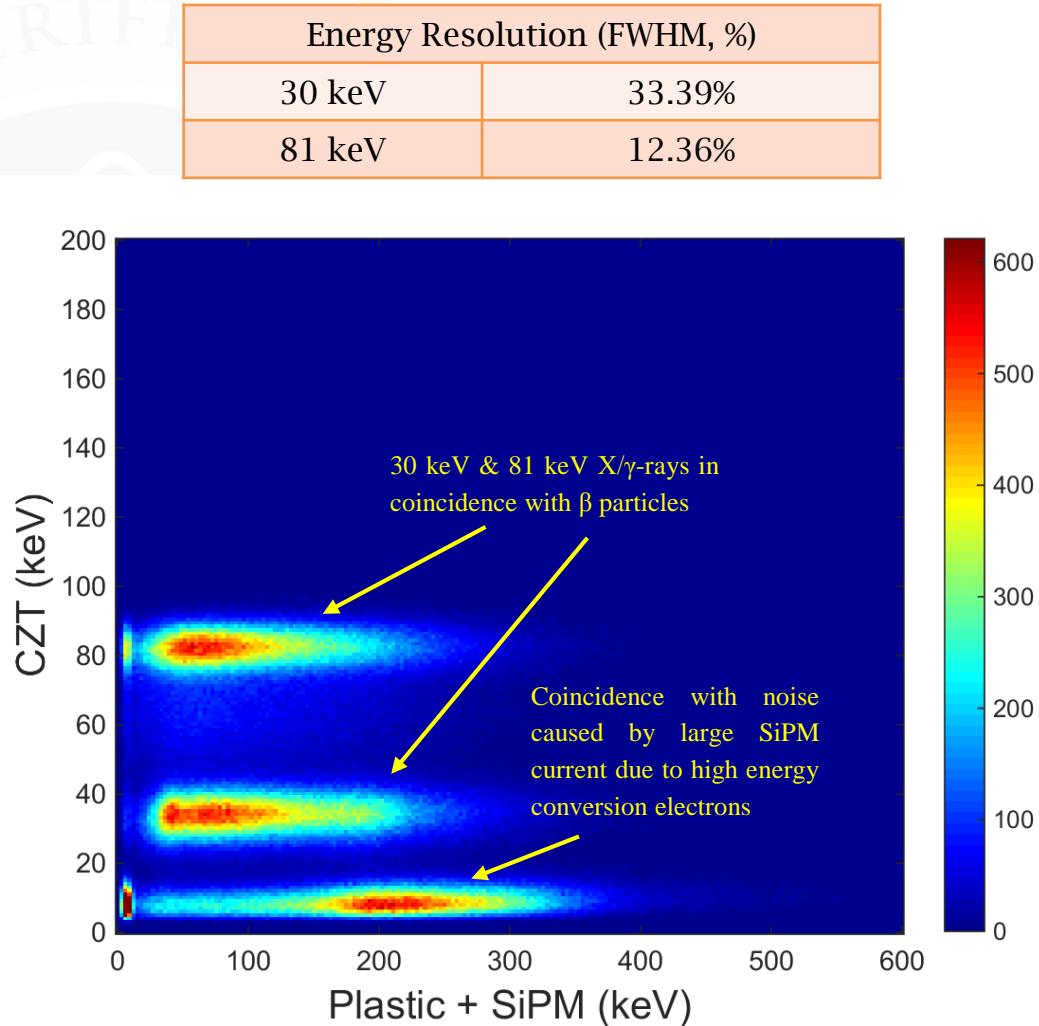
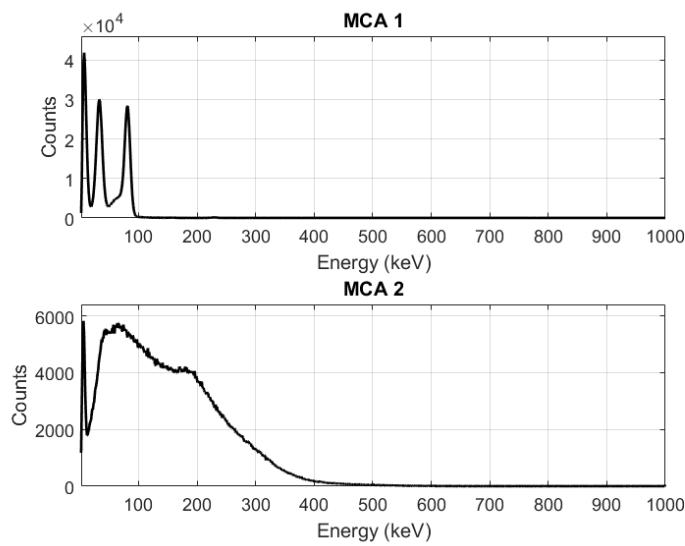
<u>Experimental Parameters</u>		
Cathode (Volts)		-1000
Grid (Volts)		-45
Trimmer Turns (counter-clockwise)		3.75
Coincidence Timing Window (Samples*)		150
Trapezoidal Filter Flat Top Time (Samples*)	CZT	180
	Plastic + SiPM	200
Trapezoidal Filter Peaking Time (Samples*)	CZT	200
	Plastic + SiPM	125
Gain (DAC Units)	CZT	2000
	Plastic + SiPM	1200
Offset (DAC Units)	CZT	3100
	Plastic + SiPM	4095

*1 Sample = 5 ns

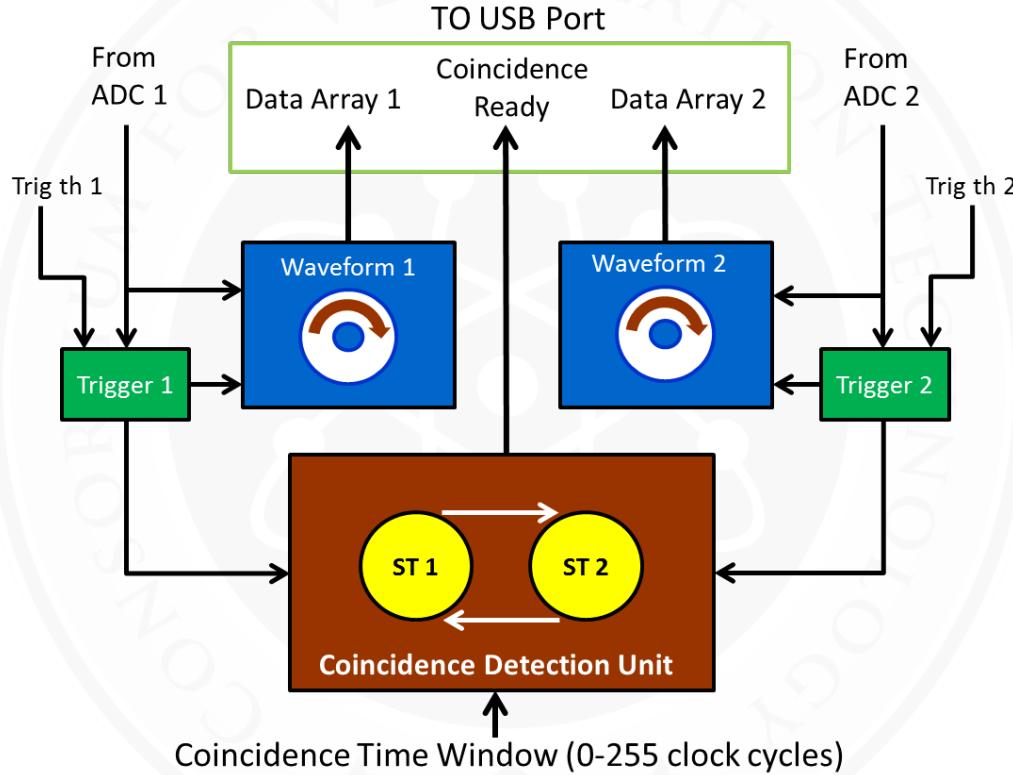


EXTRA SLIDES- Unfiltered $^{133}/^{133m}\text{Xe}$

Parameters	^{133}Xe	^{133m}Xe
Half-Life (days)	5.243	2.19
X-Ray (keV)	30	30
Gamma (keV)	81	-
Max Beta (keV)	346	-
Conversion Electron (keV)	45	199



EXTRA SLIDES- FPGA Module



EXTRA SLIDES- DPP 2.0

