Edge Illuminated CZT Strip Detectors for PET and SPECT

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La Fonda Hotel | Santa Fe, New Mexico, USA

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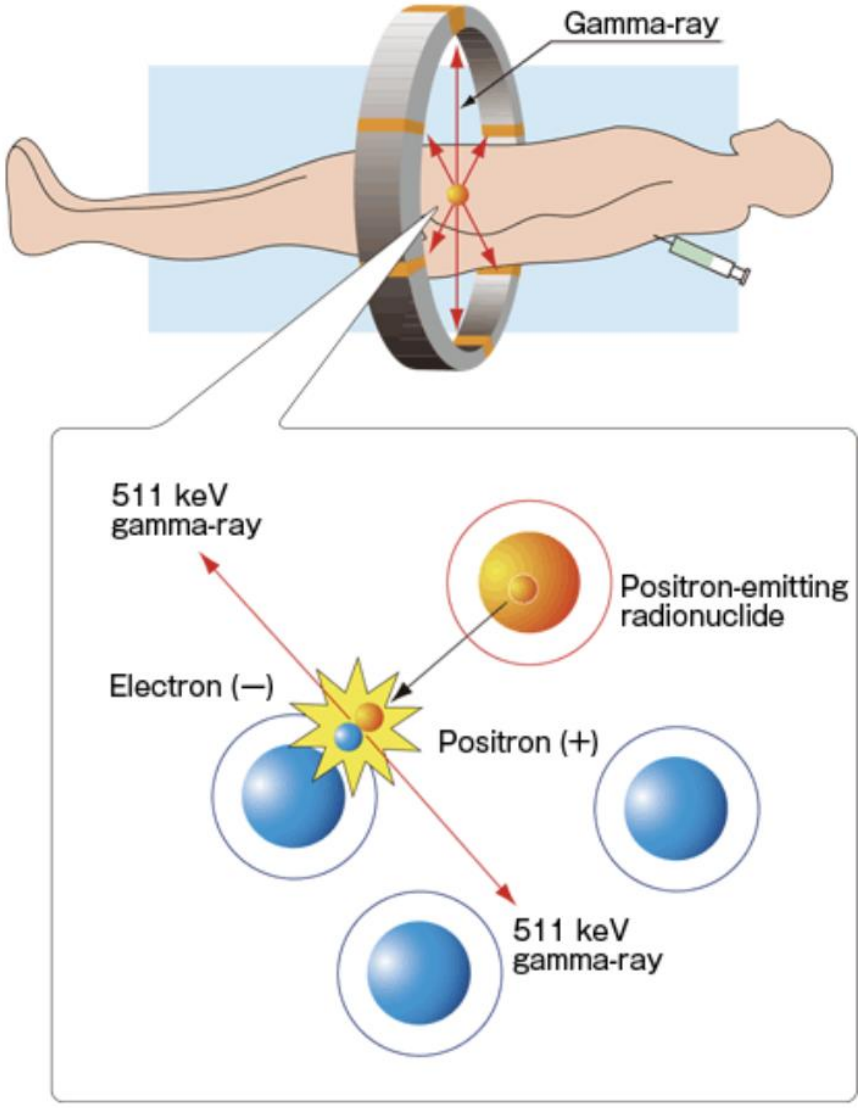
Nuclear Medicine

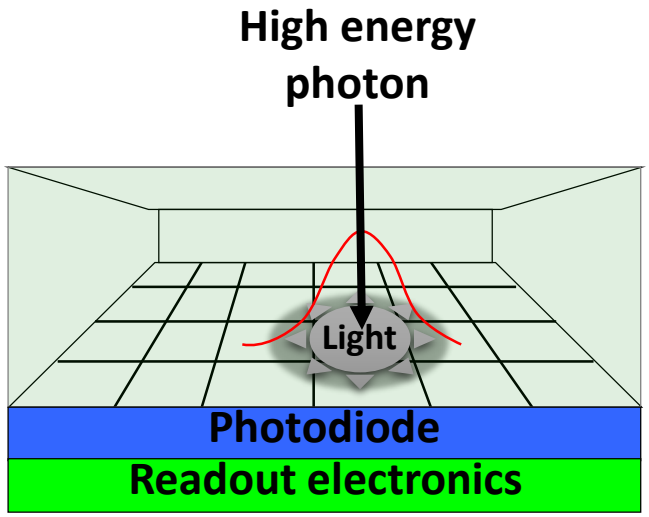


What type of radiation do we use in nuclear medicine?

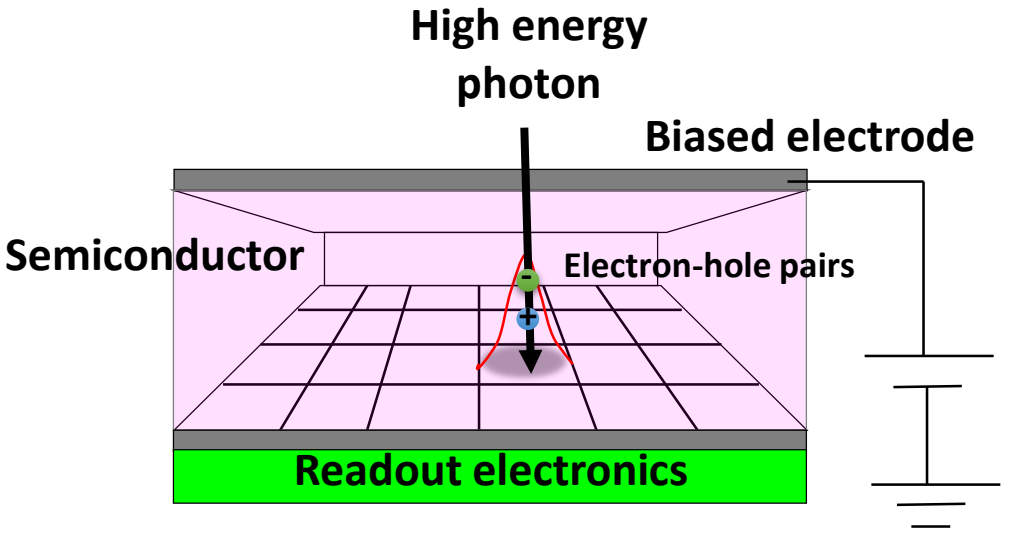
- Gamma-emitting radioisotope (Single-Photon Emission Computed Tomography) or positron-emitting radioisotope (Positron Emission Tomography)
- Oncology, Cardiology, Neurology
- Glucose metabolism, Tissue perfusion, Bone metabolism, Infection, Thyroid function , Gene expression

Detector Technology

Indirect conversion

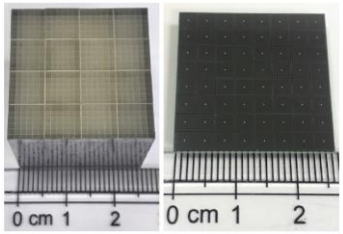


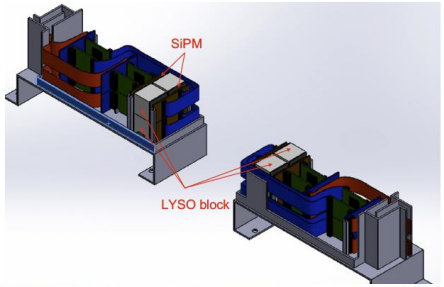
Direct conversion

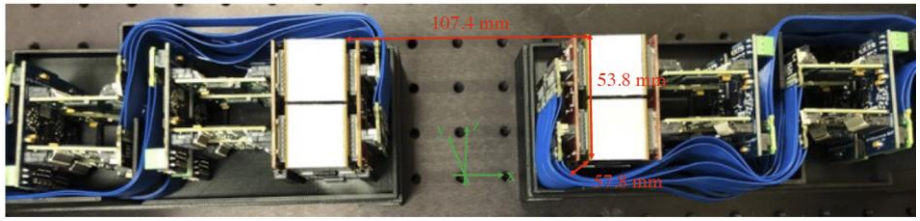


Detector Technology

Indirect conversion







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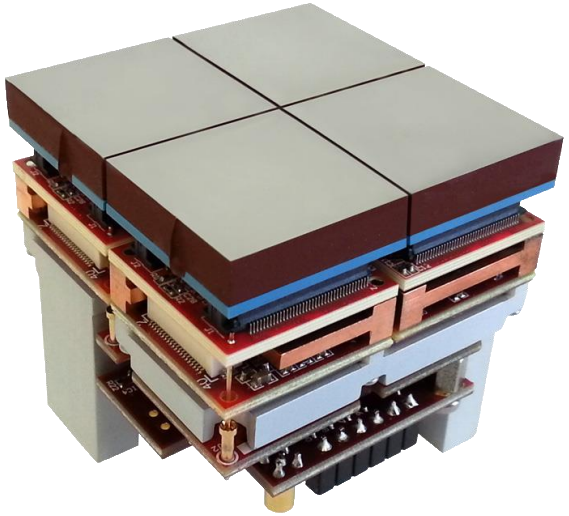


M. Li and S. Abbaszadeh, Physics in Medicine & Biology, 64 (17), 2019.

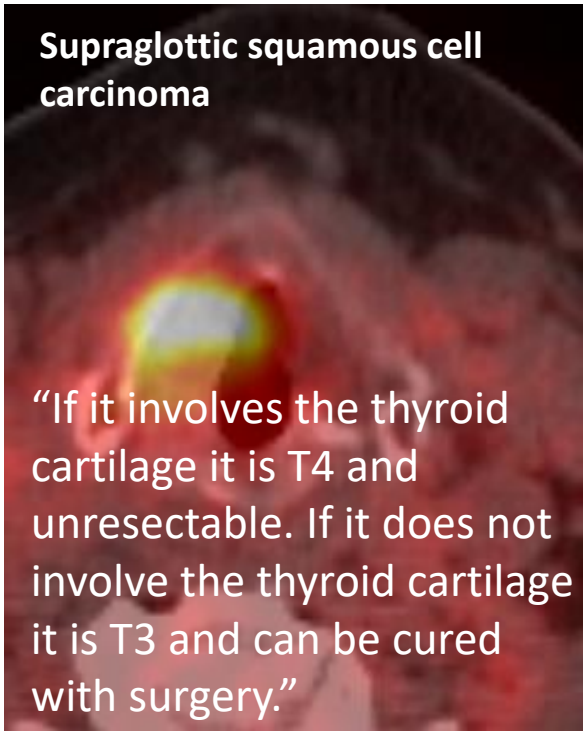
https://www.kromek.com/cadmium-zinc-telluride

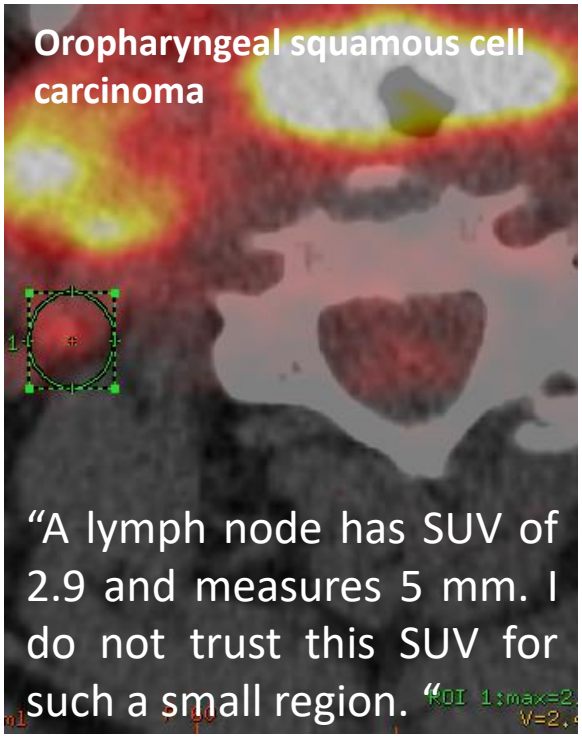
	Scintillator	CZT
Spatial resolution	Crystal elements	✓ Electrode
Spatial uniformity	3-D positioning	✓ 3-D positioning
Energy resolution at 511 keV	~ 10 % FWHM	✓ 3 % FWHM
Time resolution	< 1 ns FWHM	✗ ~ 10 ns FWHM
Packing fraction	Lower	✓ >99 %

Head and Neck Cancer

PET is commonly used in head and neck cancer (HNC) for diagnosing, staging, treatment planning, and assessing response to therapy.

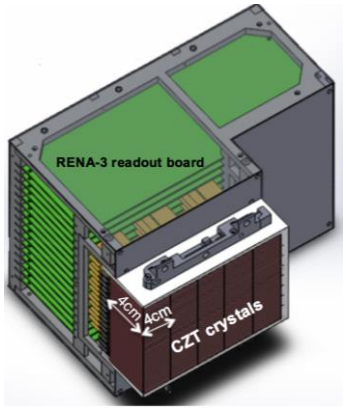
Problem: Challenging to diagnose due to the thin, soft tissues within the neck. **Limited spatial resolution of whole-body PET** (4 to 6 mm) results in a large number of false-negatives.

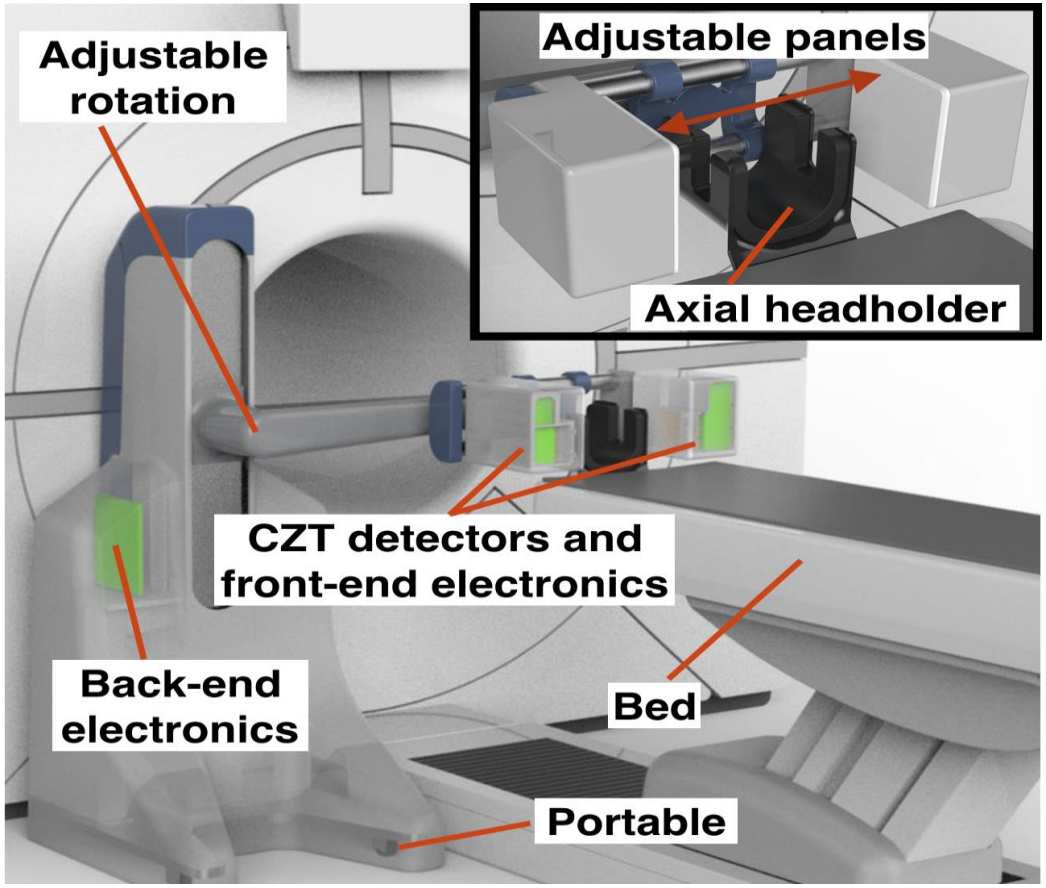




Head and Neck Cancer

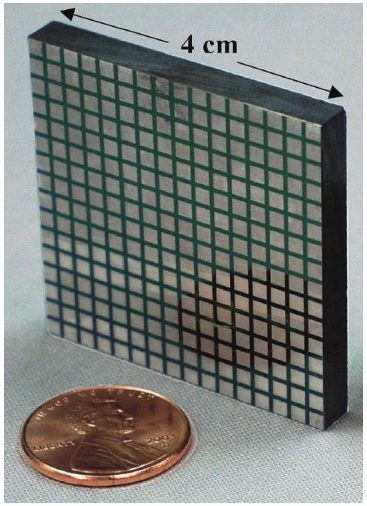
Dual-panel system geometry
Follow-on scan
• The dedicated system will image the patient right after the whole-body scan, without requiring extra dose

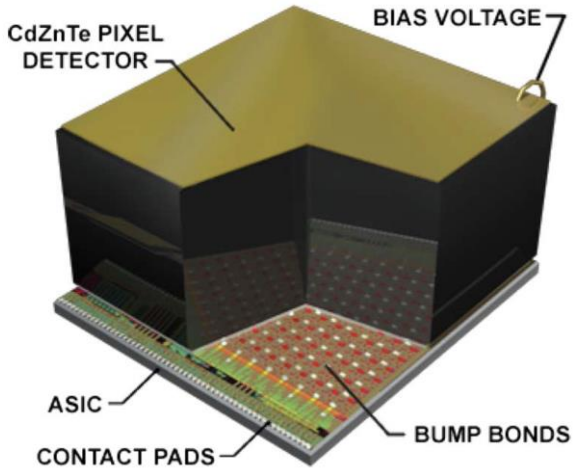




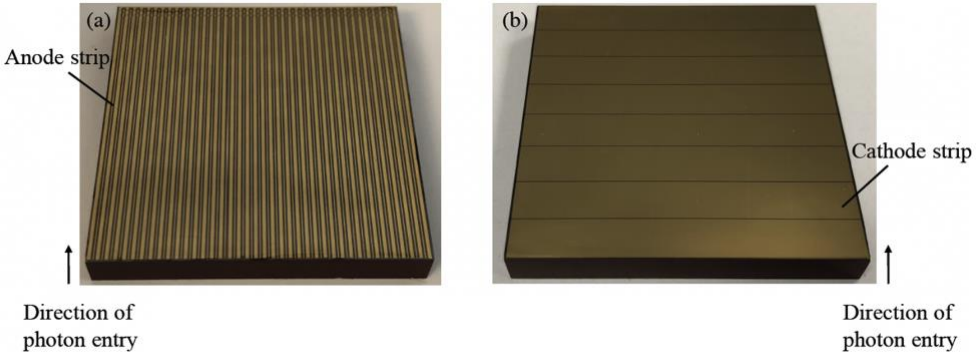
Detector Technology

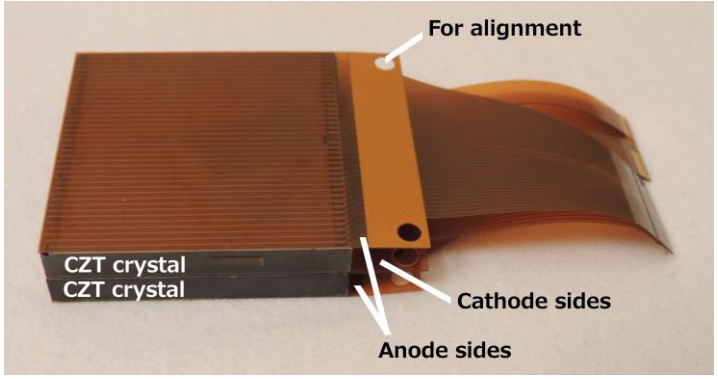
Pixel array configuration





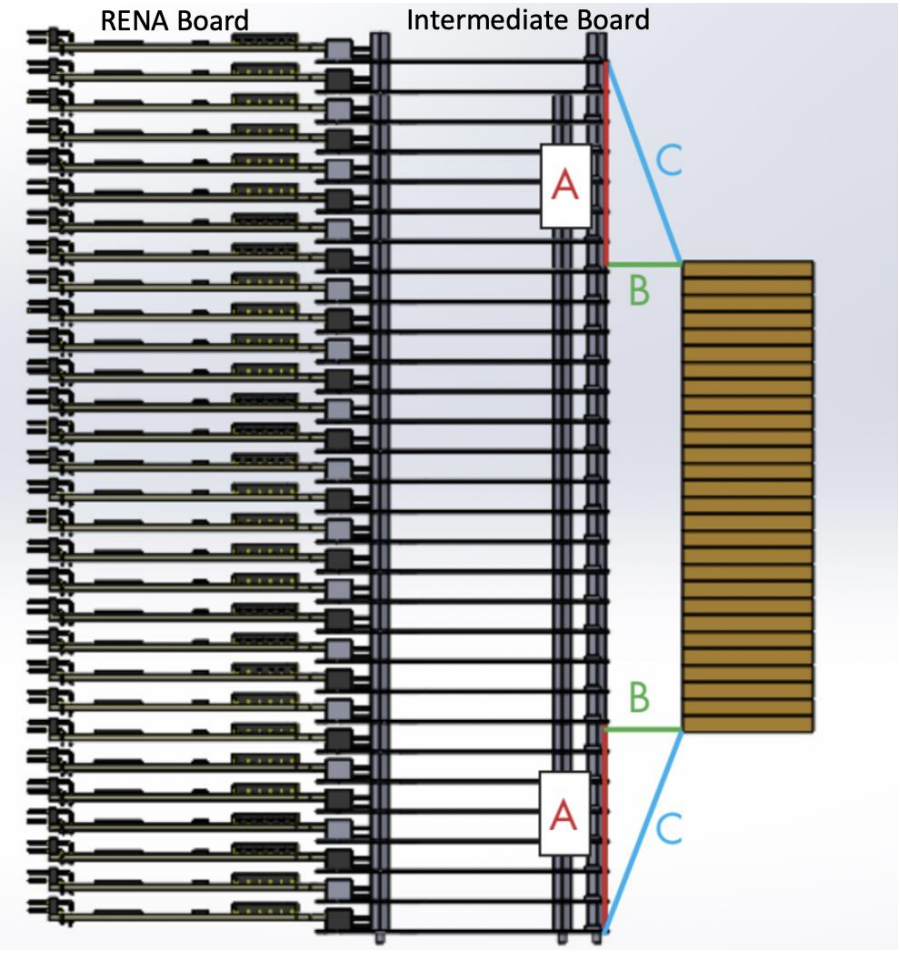
Cross-strip array configuration

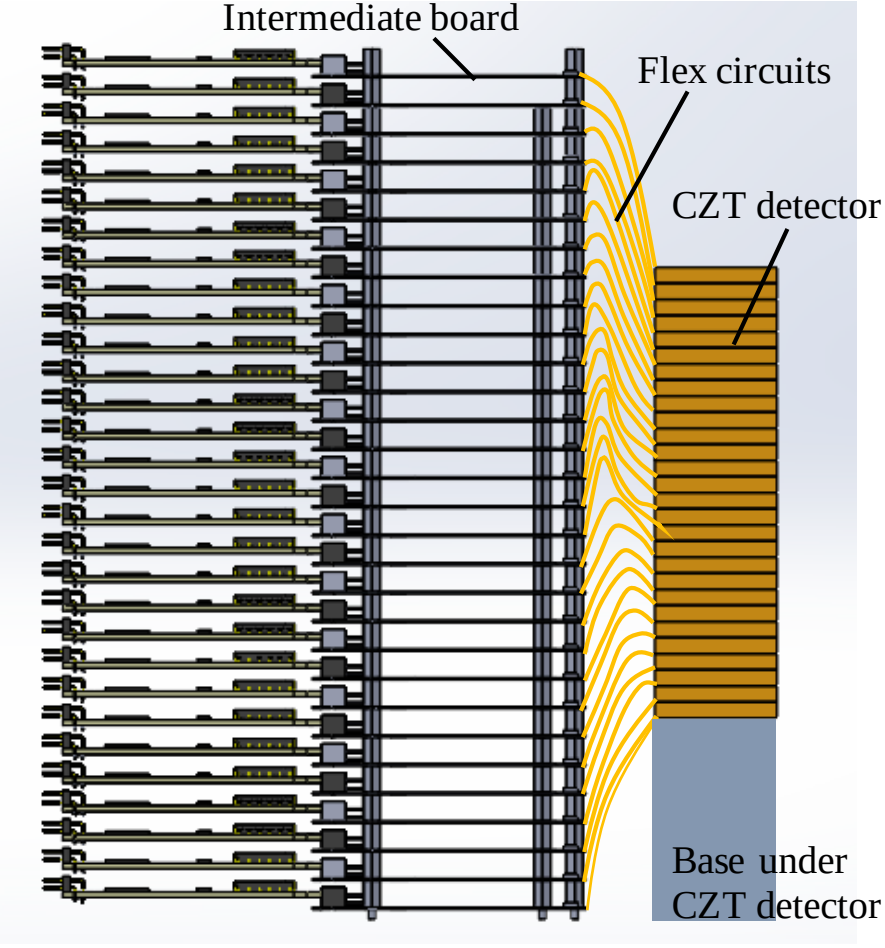




Abbaszadeh et al., Journal of Medical Imaging 4 (1), 2017.
Gu and Levin, Phys. Med. Biol., vol. 59, 2599, 2014.

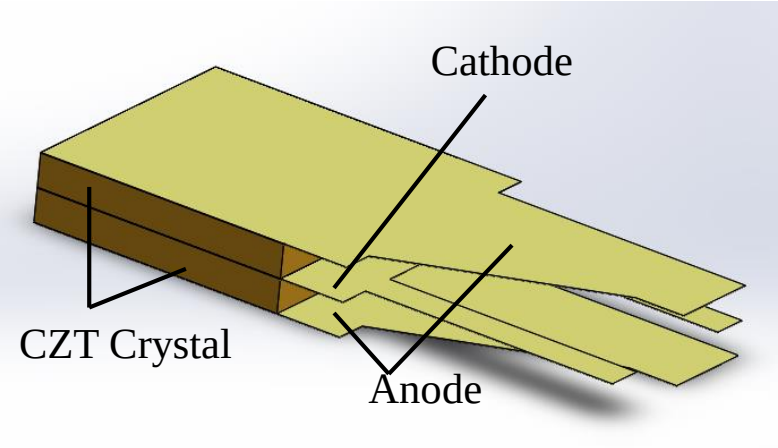
Flexible Circuit Design

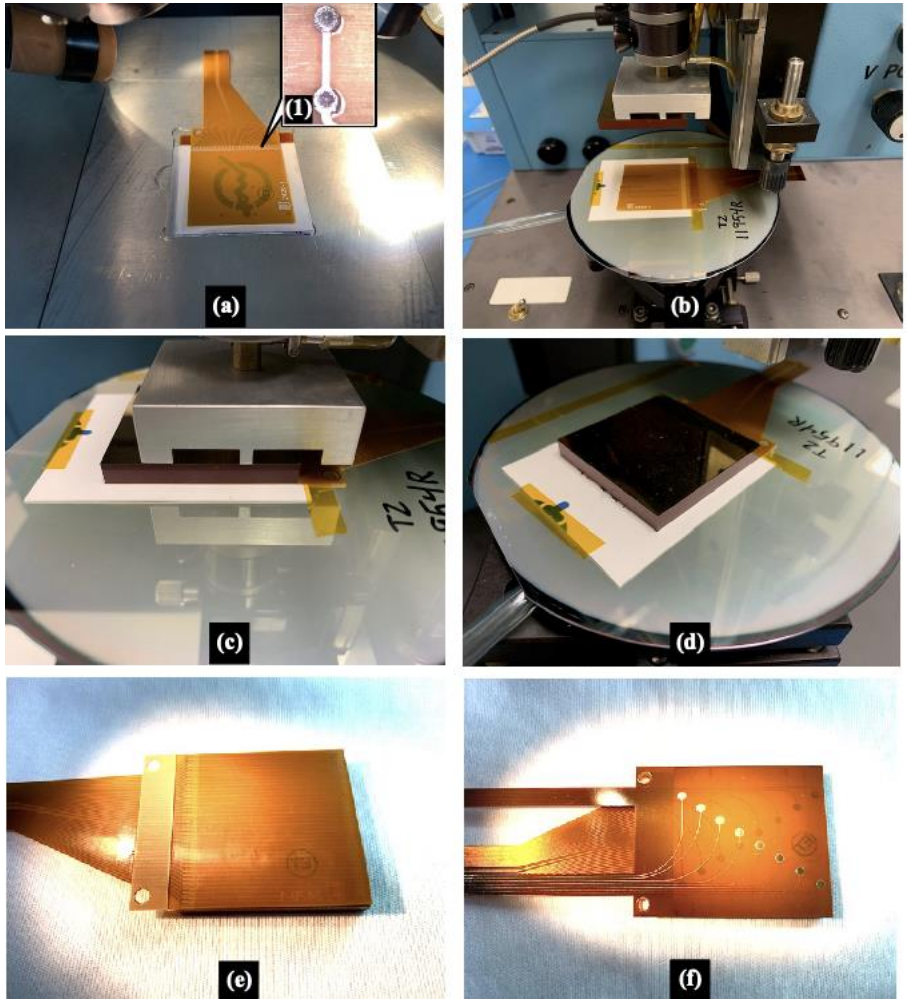




CZT Crystal Pair and Bonding

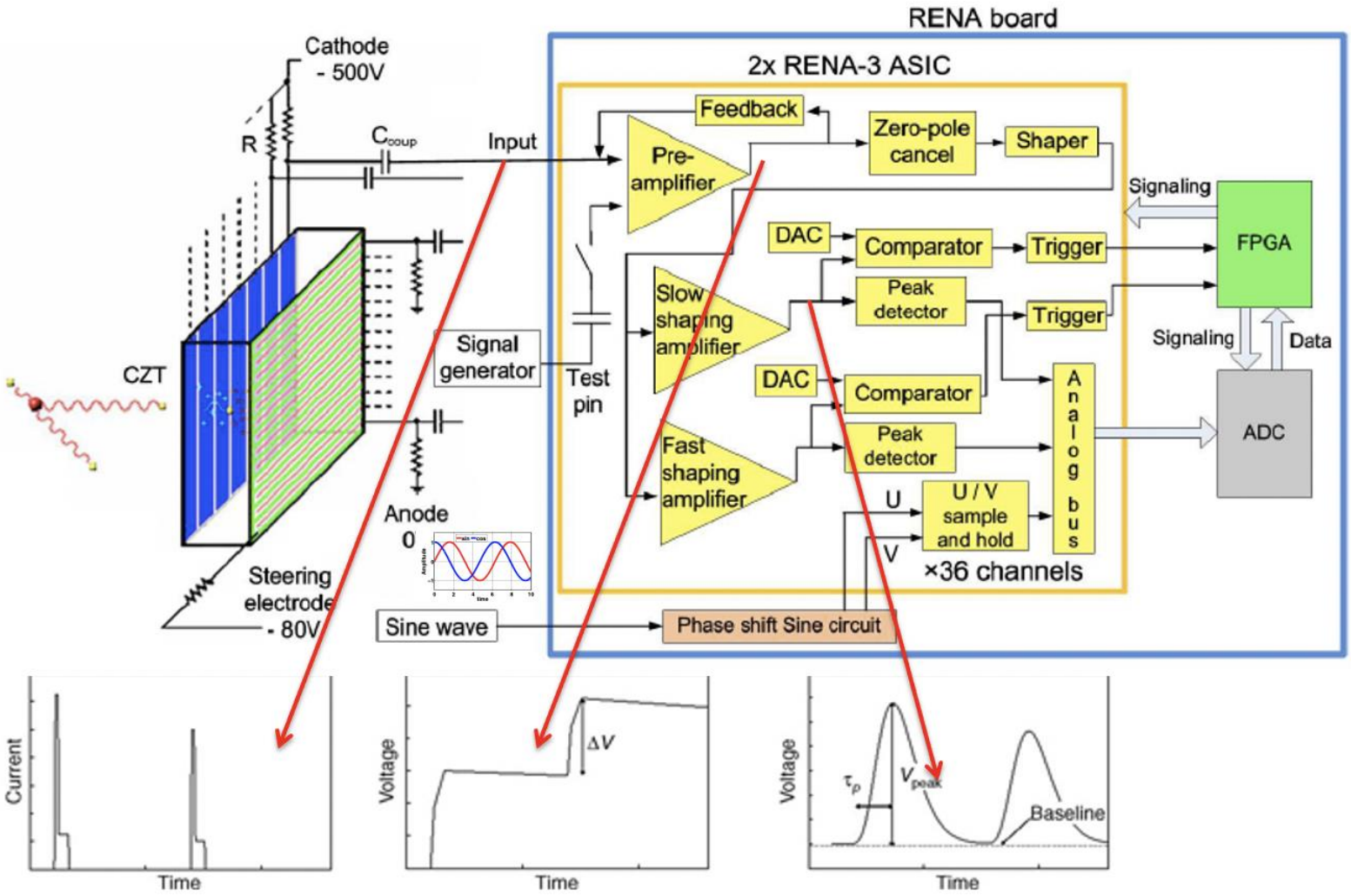
CZT Crystal Pair



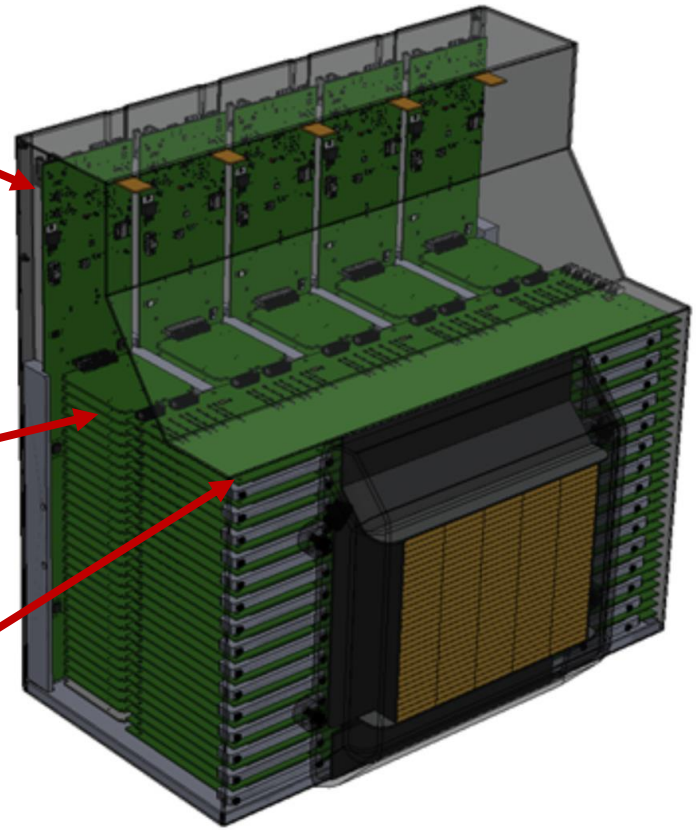


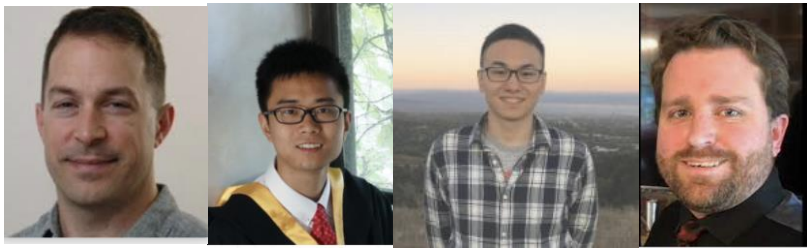
Collaboration with James Clayton
Polymer Assembly Technology, Inc.

RENA-3 ASIC


RENA board
2x RENA-3 ASIC
Cathode
- 500V
R
C_{coup}
Input
Feedback
Pre-
amplifier
Zero-pole
cancel
Shaper
Signaling
FPGA
DAC
Comparator
Trigger
Peak
detector
Trigger
Slow
shaping
amplifier
Signaling
Data
CZT
Signal
generator
Test
pin
DAC
Comparator
Peak
detector
Fast
shaping
amplifier
Analog bus
ADC
U
V
U / V
sample
and hold
×36 channels
Anode
0
Steering
electrode
- 80V
Sine wave
Phase shift Sine circuit
Current
Time
Voltage
ΔV
Time
Voltage
τ_p
V_{peak}
Baseline
Time

Readout Electronic





Craig Levin (Stanford University), Mohan Li (UIUC), Yuli Wang(UCSC), Ryan Herbst(SLAC)

Increasing Sensitivity

A large number of events undergo Compton scatter within the detector. These events are typically discarded.

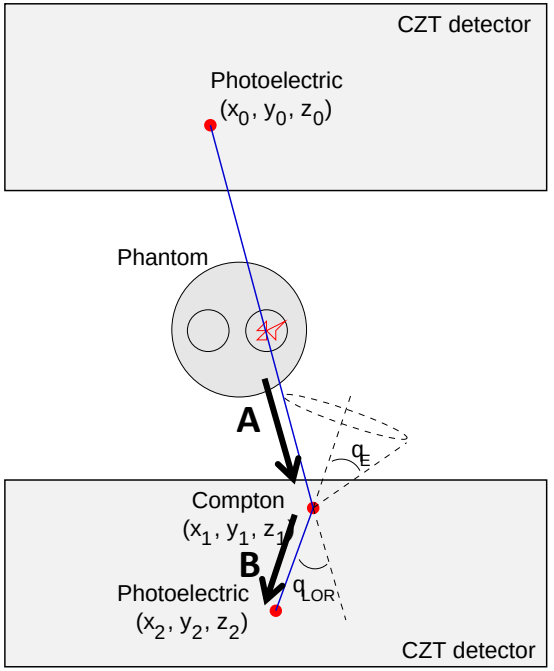
$$\theta_{LOR} = \cos^{-1}\left(\frac{\mathbf{A}\cdot\mathbf{B}}{|\mathbf{A}\cdot\mathbf{B}|}\right)$$

$$\theta_E = \cos^{-1}\left(1 - mc^2\left(\frac{1}{E_s} - \frac{1}{E_i}\right)\right)$$

$$\theta_{err} = |\theta_{LOR} - \theta_E|$$

E_s: scattered photon energy

E_i: Incident photon energy

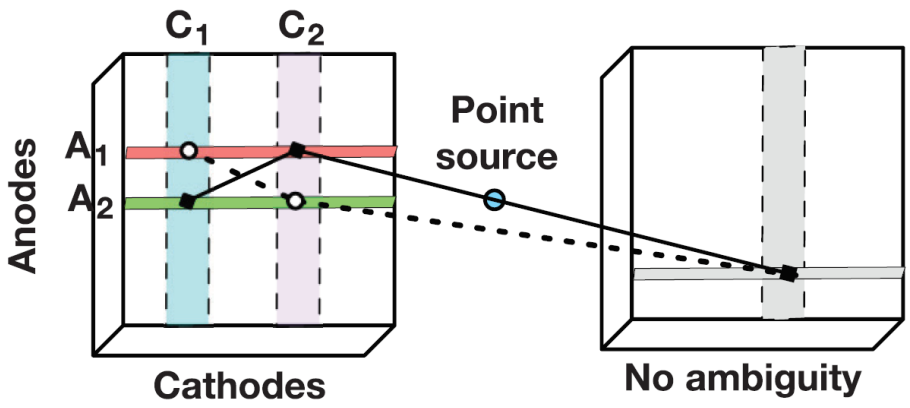


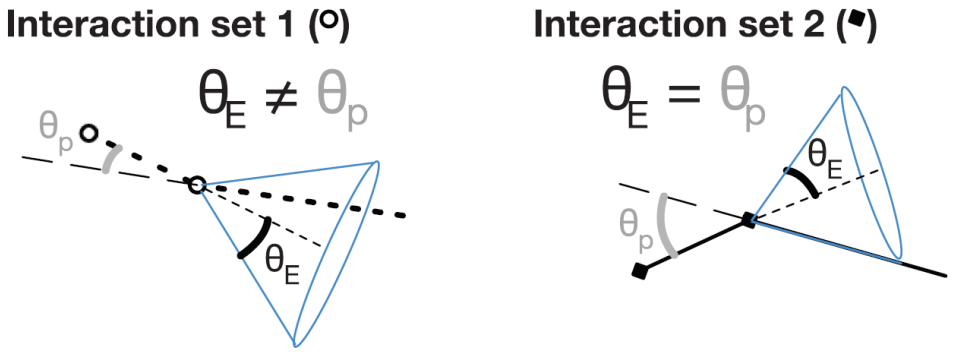
Idea: Interactions with large θ_{err} are likely not from the same event, therefore use a threshold cutoff for True/Random events

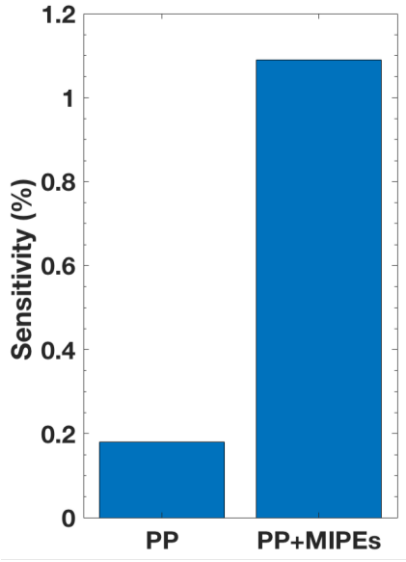
- Especially of interest for cross-strip CZT
- Consider all possible interaction sets and choose the set with the smallest θ_{err}

Abbaszadeh et al, Phys. Med. Biol., 2018.

Increasing Sensitivity



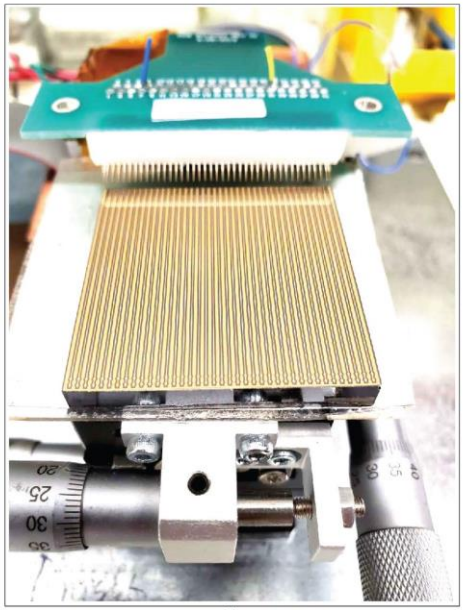




N. Nasir and S. Abbaszadeh, SPIE Medical Imaging, v.11596, pp .1011-1018 (2020)
E. Nikolakakis and S. Abbaszaeh, SPIE Medical Imaging (2023)

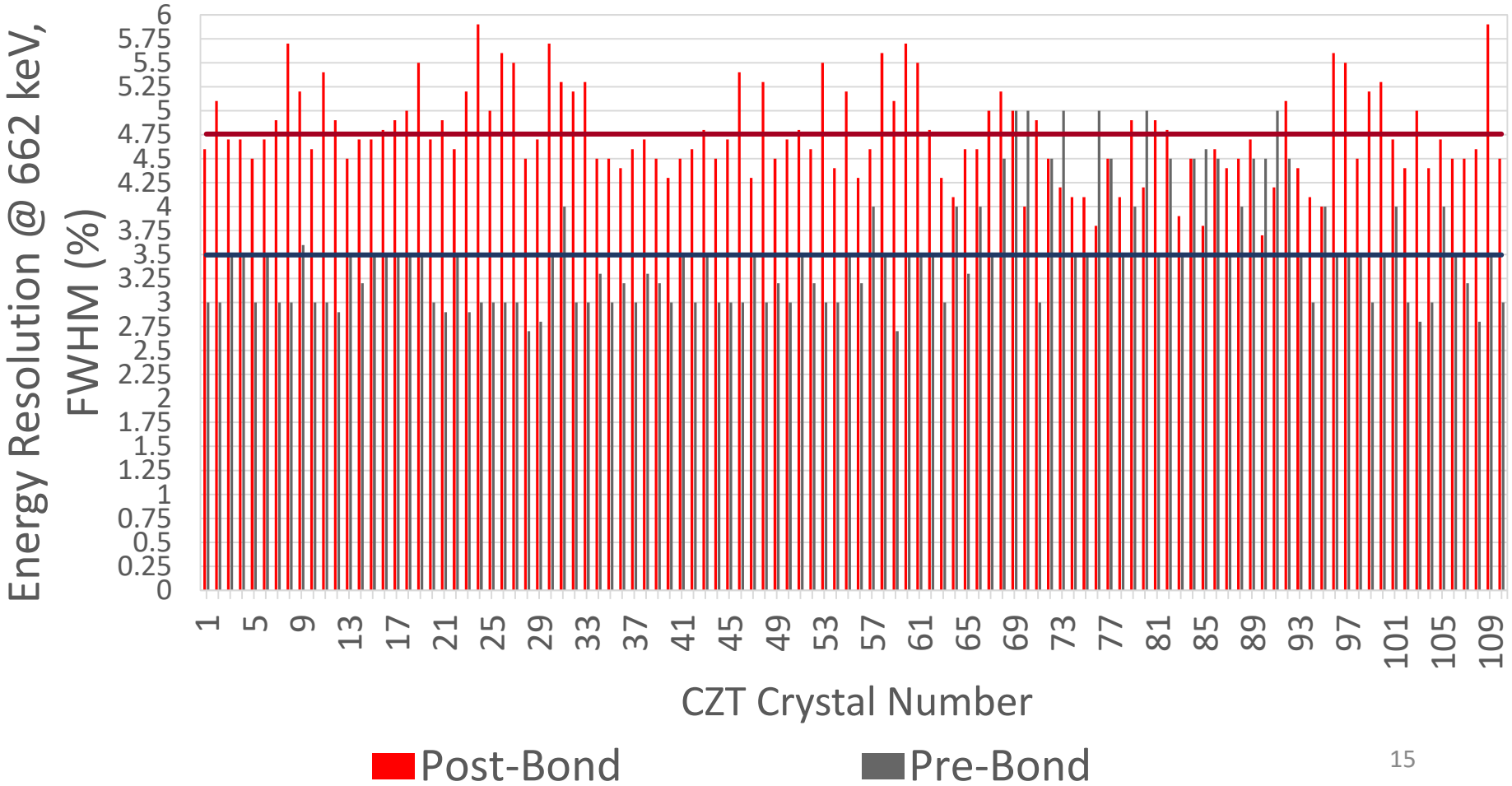
Energy Resolution of 110 CZT Crystals

- 110 crystals measured
- Pre-bonded (a)
  - Measured directly on the crystal surface electrodes
  - @662 keV – FWHM average: 3.50% std dev 0.59%
- Post-bonded (b)
  - Modules measured individually
  - Measured through readout electronics
  - @662 keV – FWHM average: 4.75% std dev 0.48%
  - @511 keV – FWHM average: 5.82% std dev 0.59%

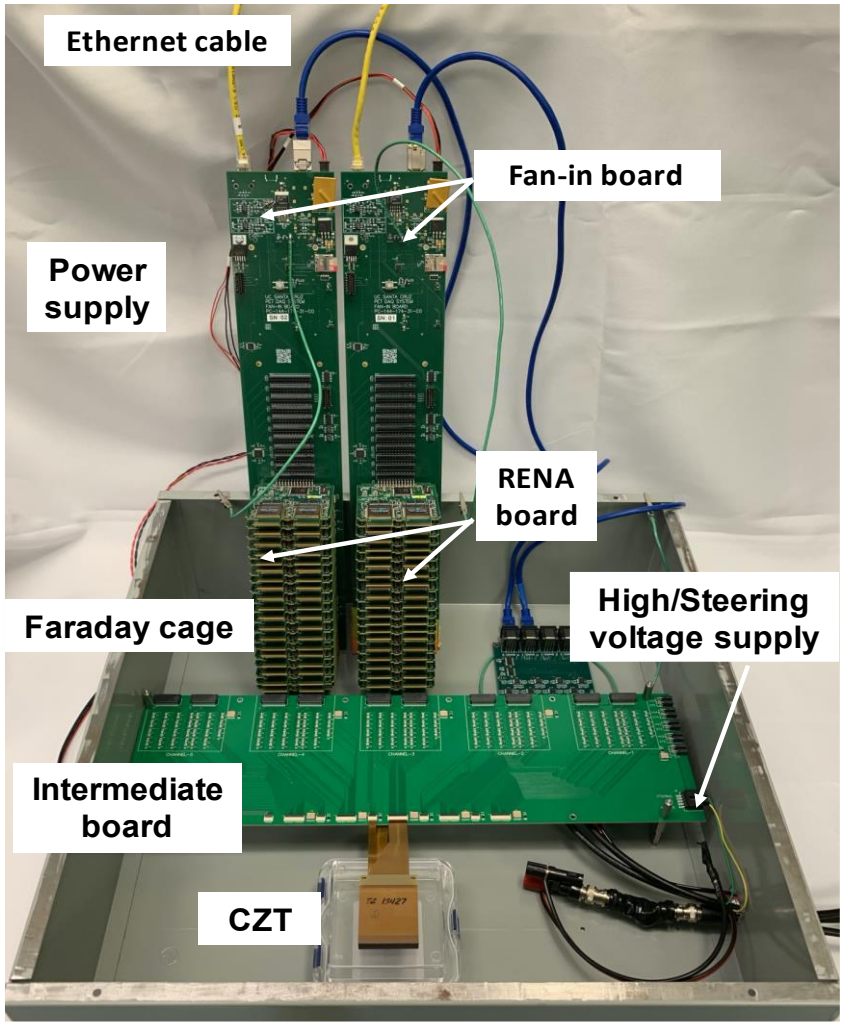

(a)

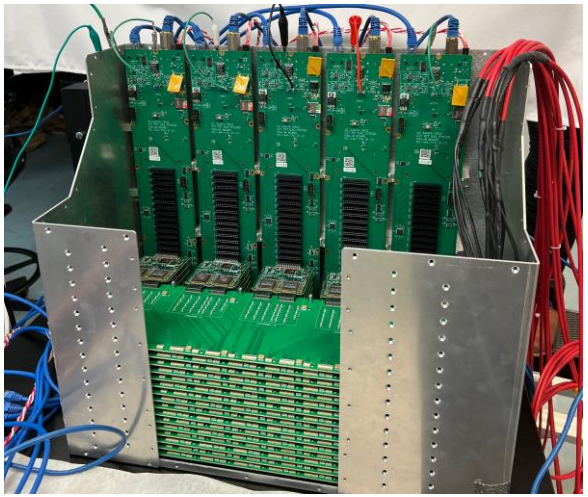

(b)

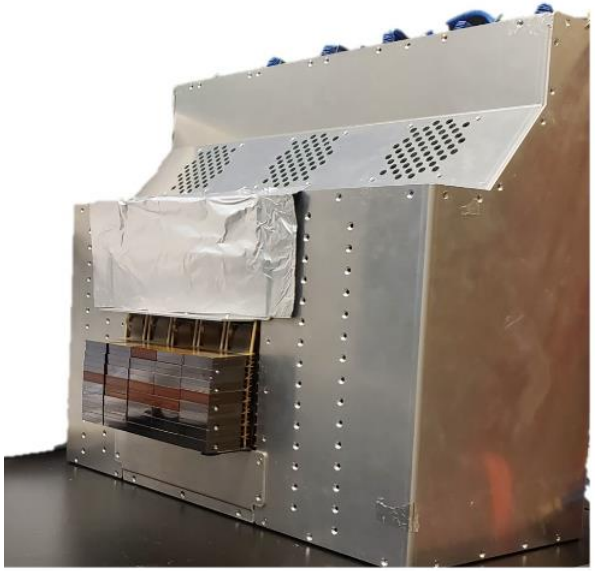
Energy Resolution of 110 CZT Crystals



PET System Scale-Up Panel 1



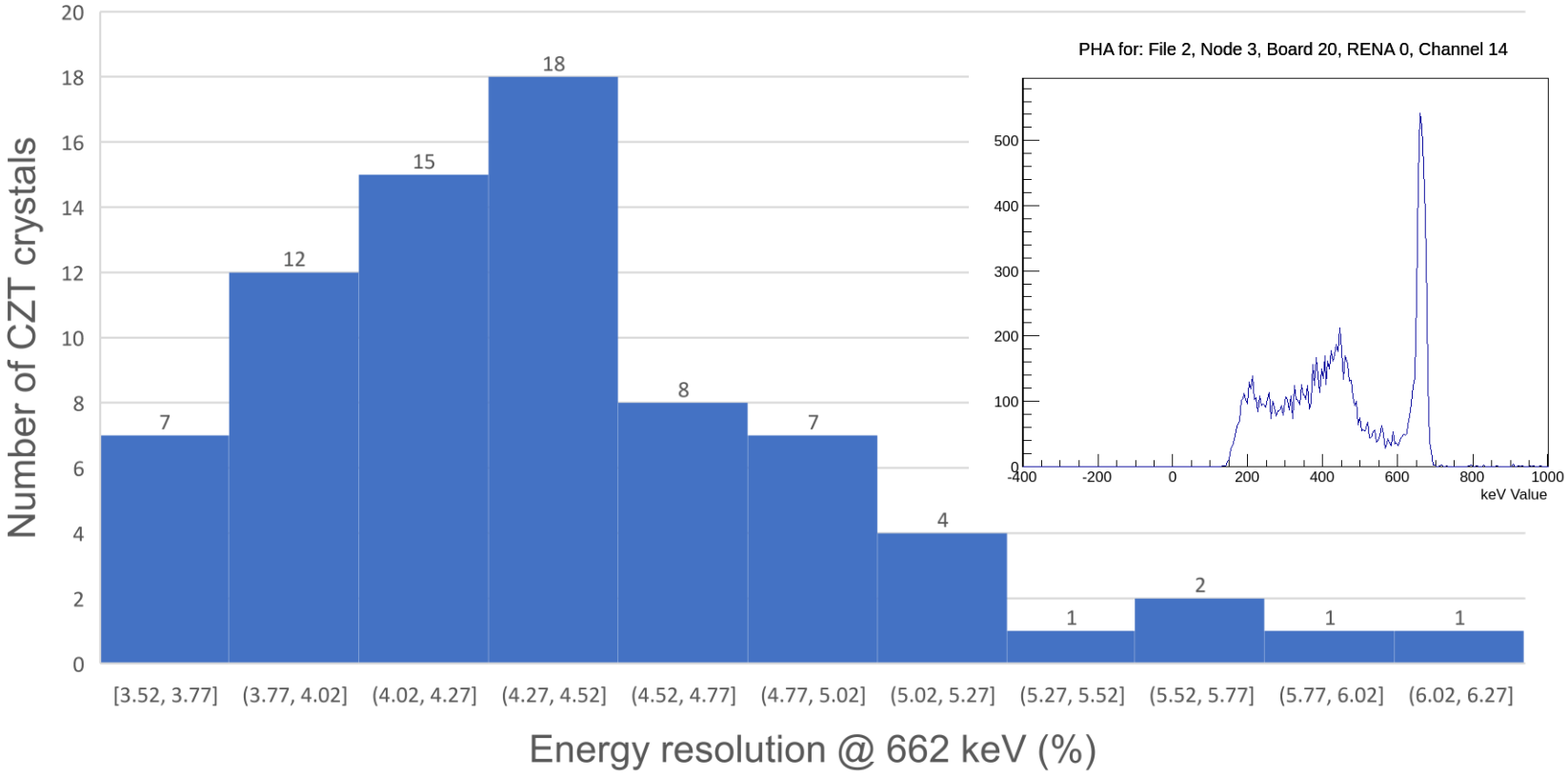




Energy Resolution for Panel 1 Scale-Up

Without depth dependent correction

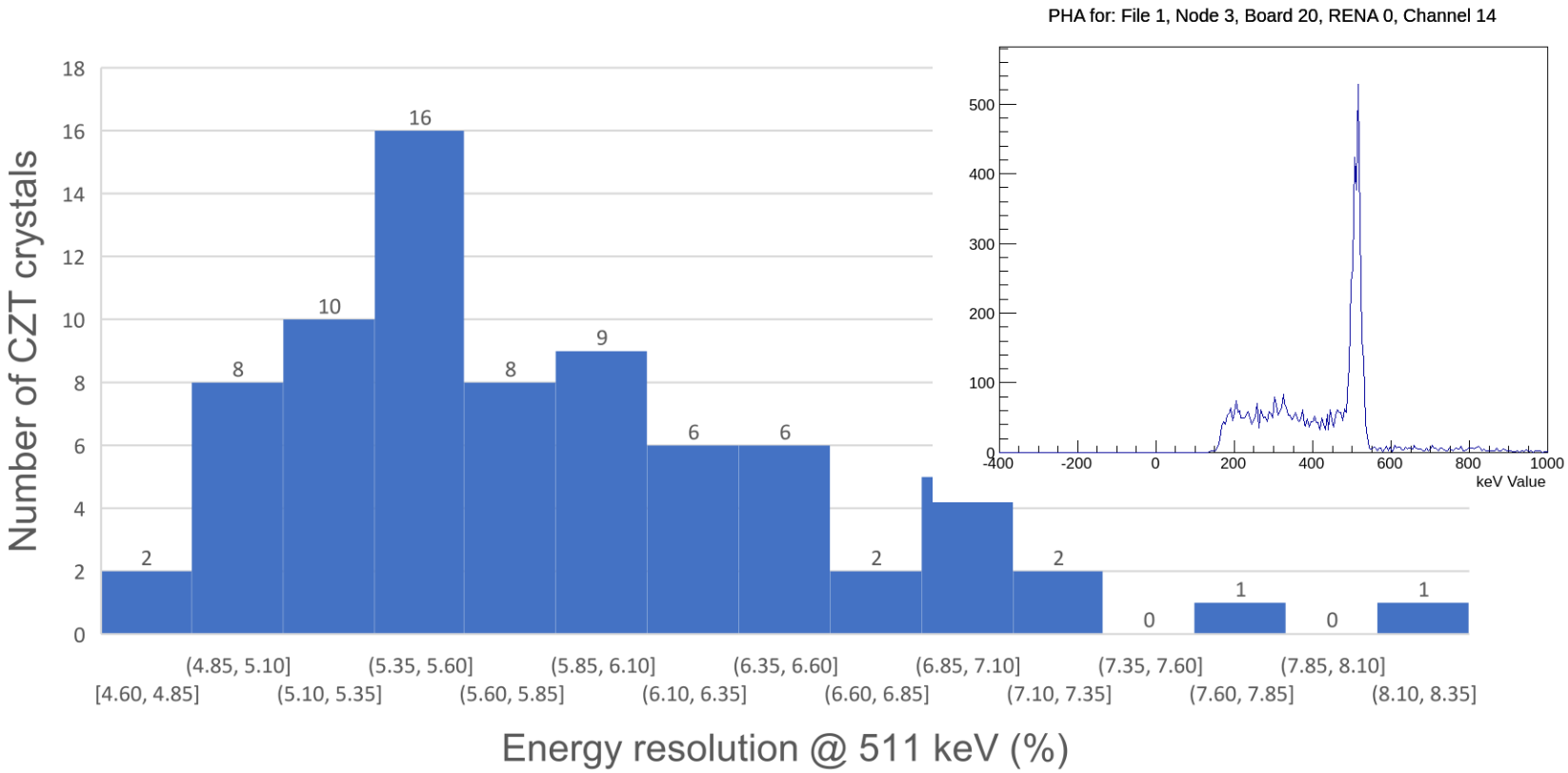
Avg: 4.40%
Std dev: 1.09%



Energy Resolution for Panel 1 Scale-Up

Without depth dependent correction

Avg: 5.85%
Std dev: 1.46%



Conclusion

- The edge-on CZT configuration provides high quantum efficiency for high energy photons (~511 keV)
- The cross-strip configuration provides cost efficient readout electronics
- The large volume CZT crystals with high packing fractions provides opportunities for detecting multiple interaction photon events and recovering accurate line of response
- The average energy resolution of 110 individually tested pre-bonded crystal was 3.5 %.
- The system-wide post-boded energy resolution of all crystals was 4.4%.
- No significant cross-talk were observed on the energy resolution when crystals were stacked on top of each other.

CZT Detector Design