



Edge Illuminated CZT Strip Detectors for **PET** and SPECT



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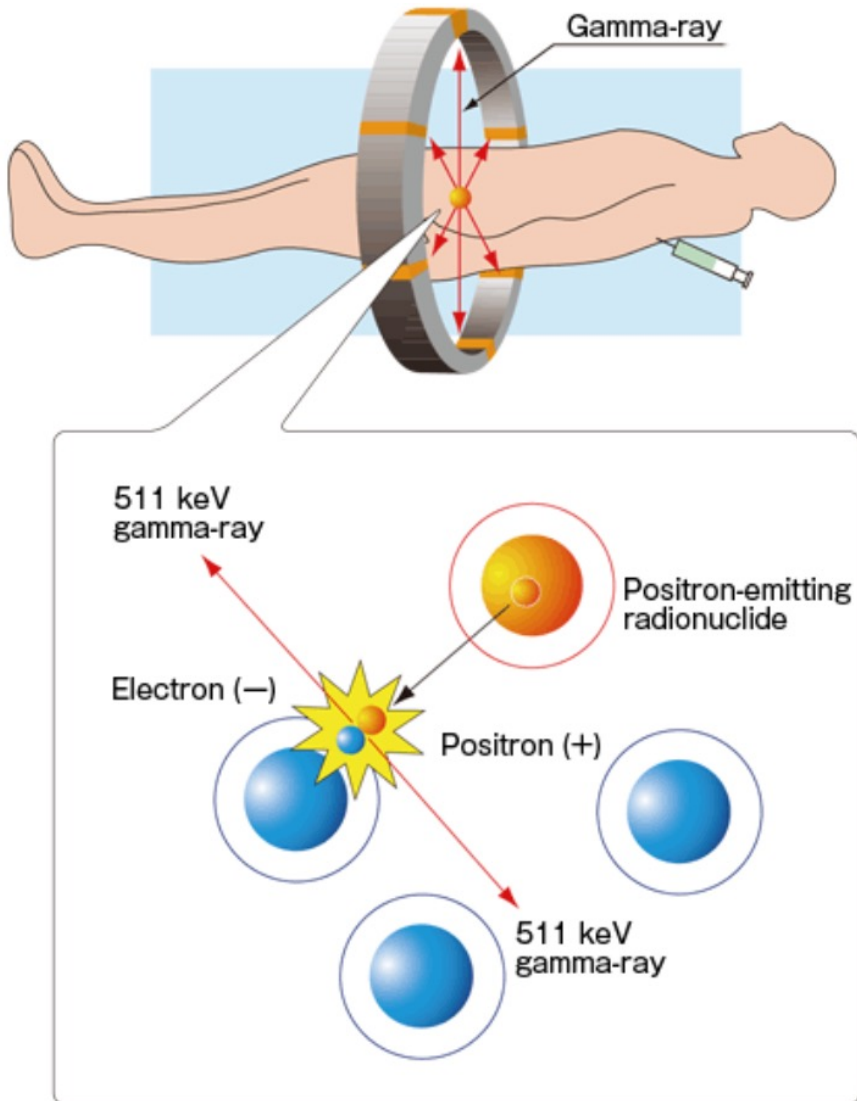
<https://ril.soe.ucsc.edu>



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La Fonda Hotel | Santa Fe, New Mexico, USA

Nuclear Medicine



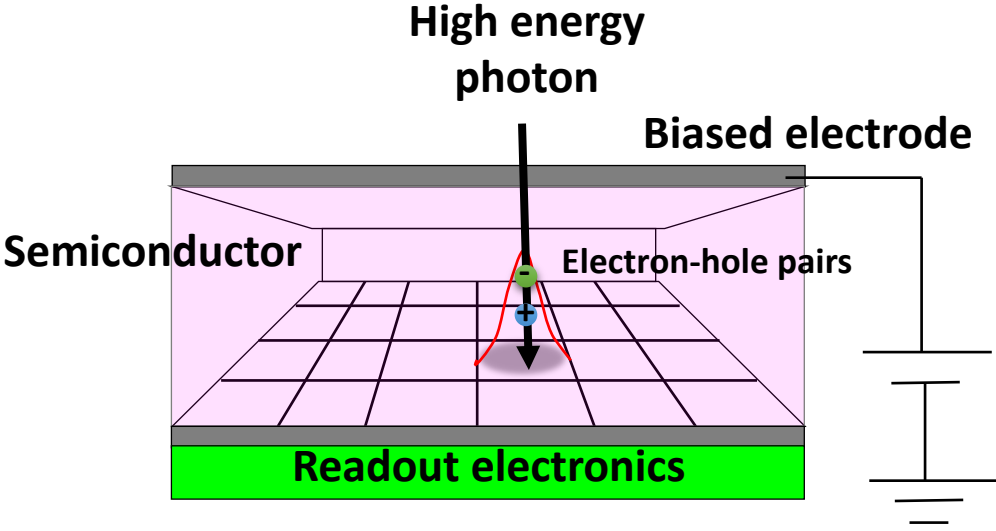
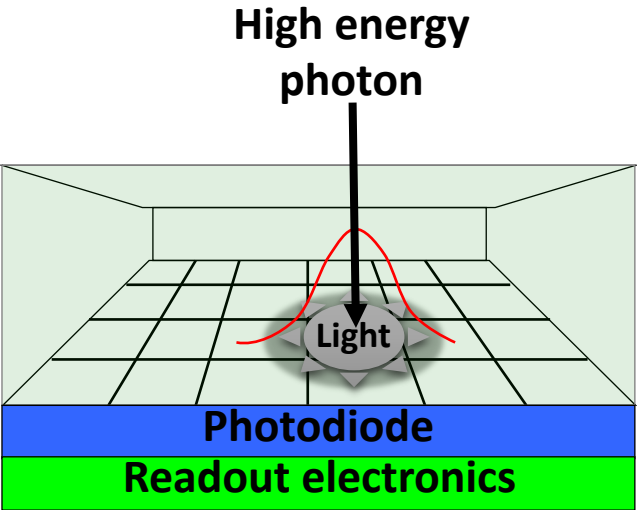
What type of radiation do we use in nuclear medicine?

- 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

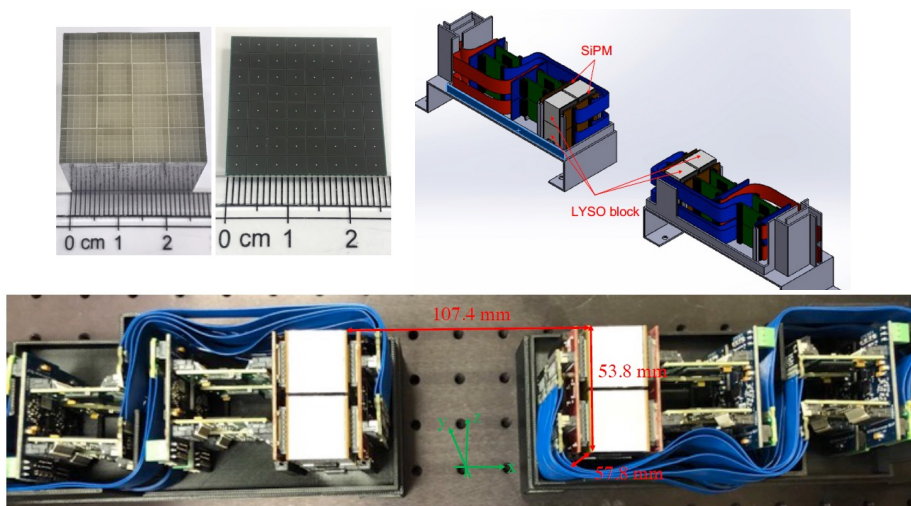
Indirect conversion

Direct conversion

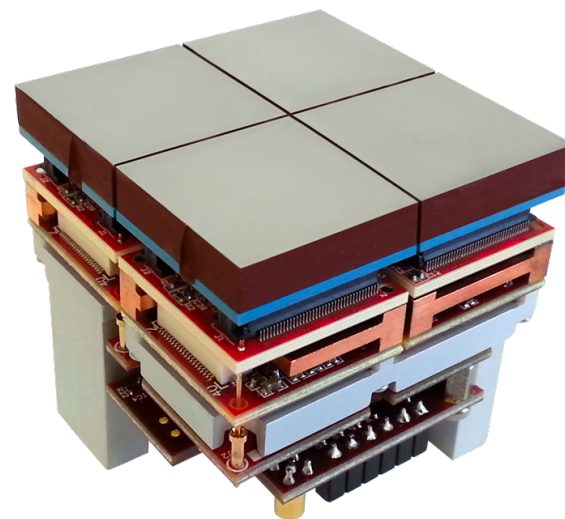


Detector Technology

Indirect conversion



Direct conversion



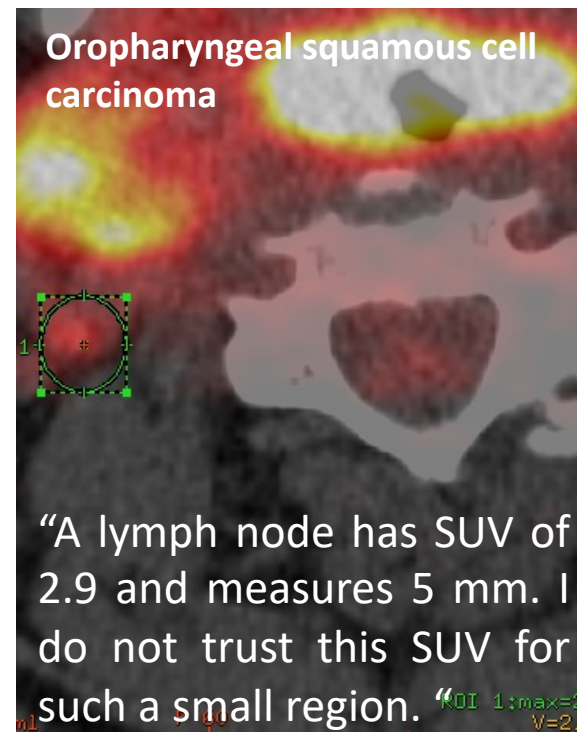
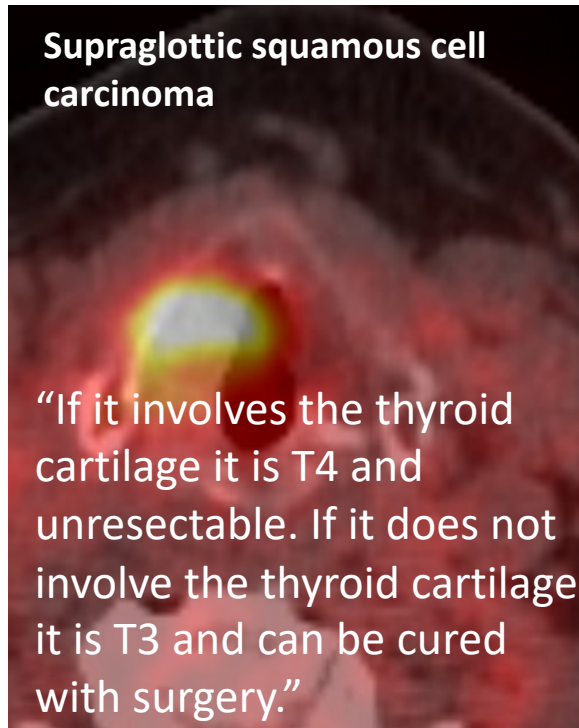
M. Li and S. Abbaszadeh, Physics in Medicine & Biology, 64 (17), 2019. <https://www.kromek.com/cadmium-zinc-telluride>

	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.

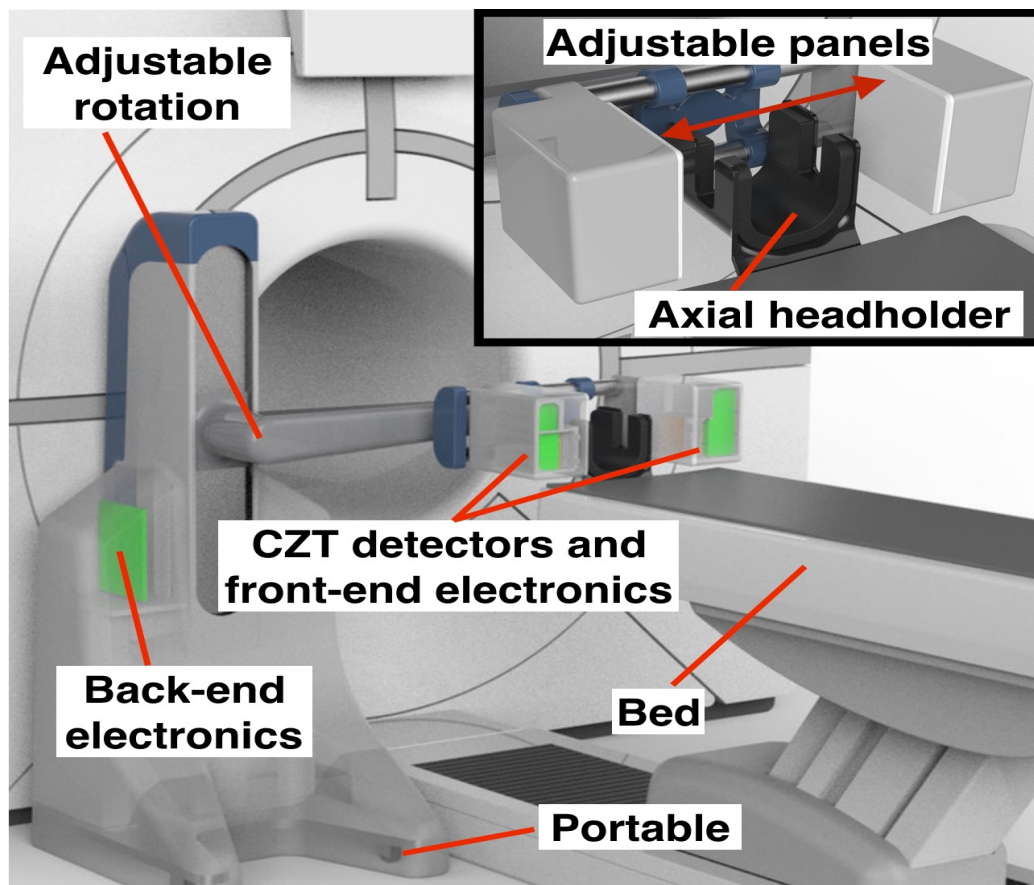
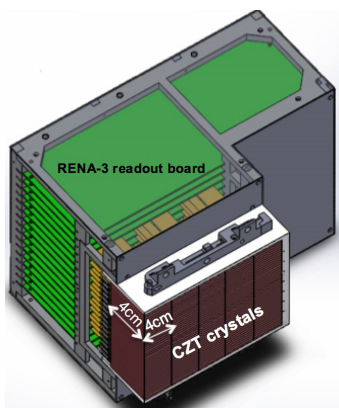


Head and Neck Cancer

Dual-panel system geometry

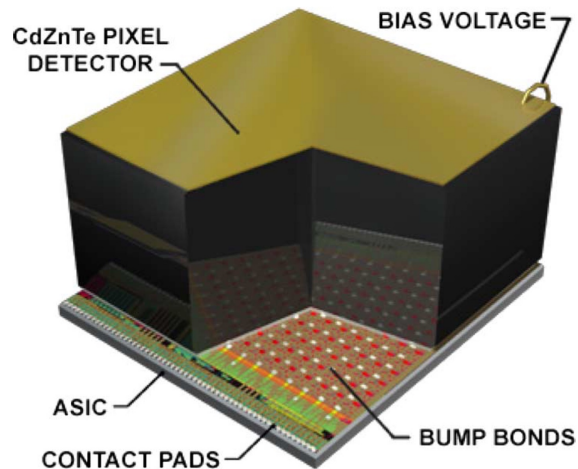
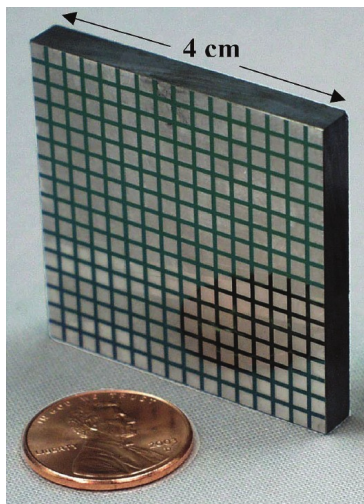
Follow-on scan

- The dedicated system will image the patient right after the whole-body scan, without requiring extra dose

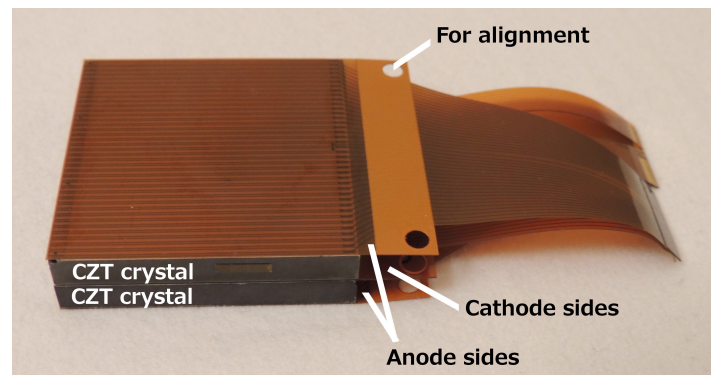
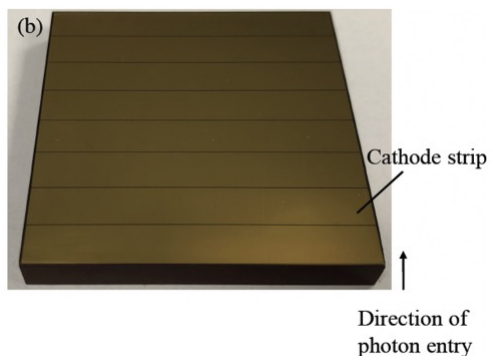
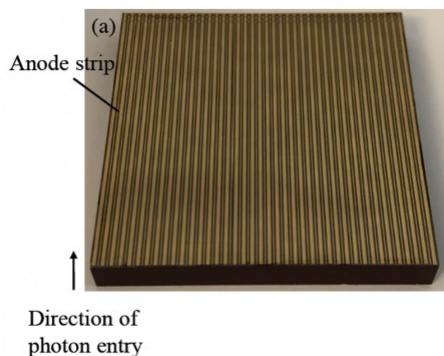


Detector Technology

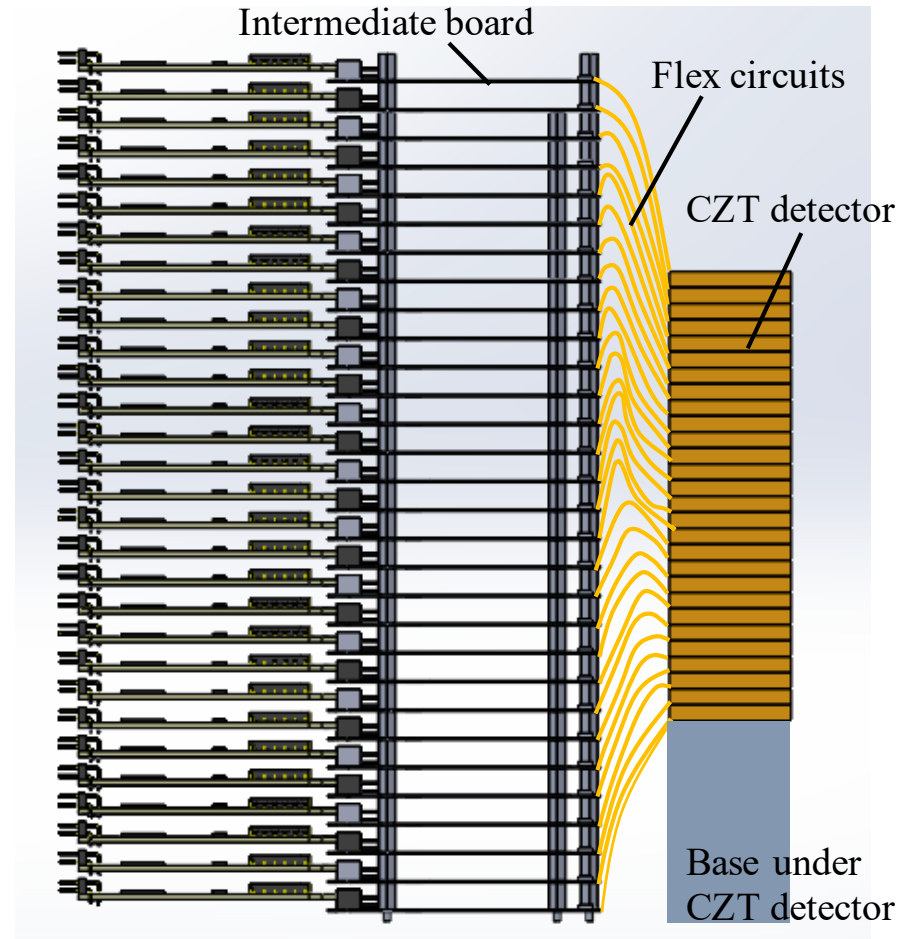
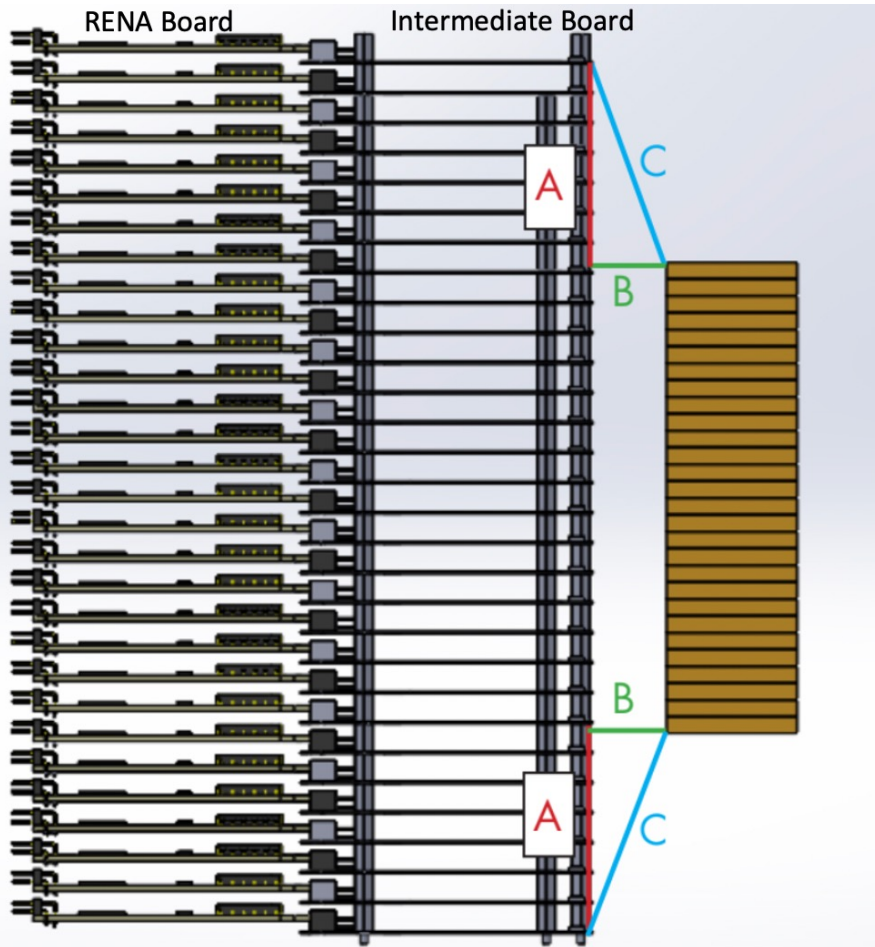
Pixel array configuration



Cross-strip array configuration

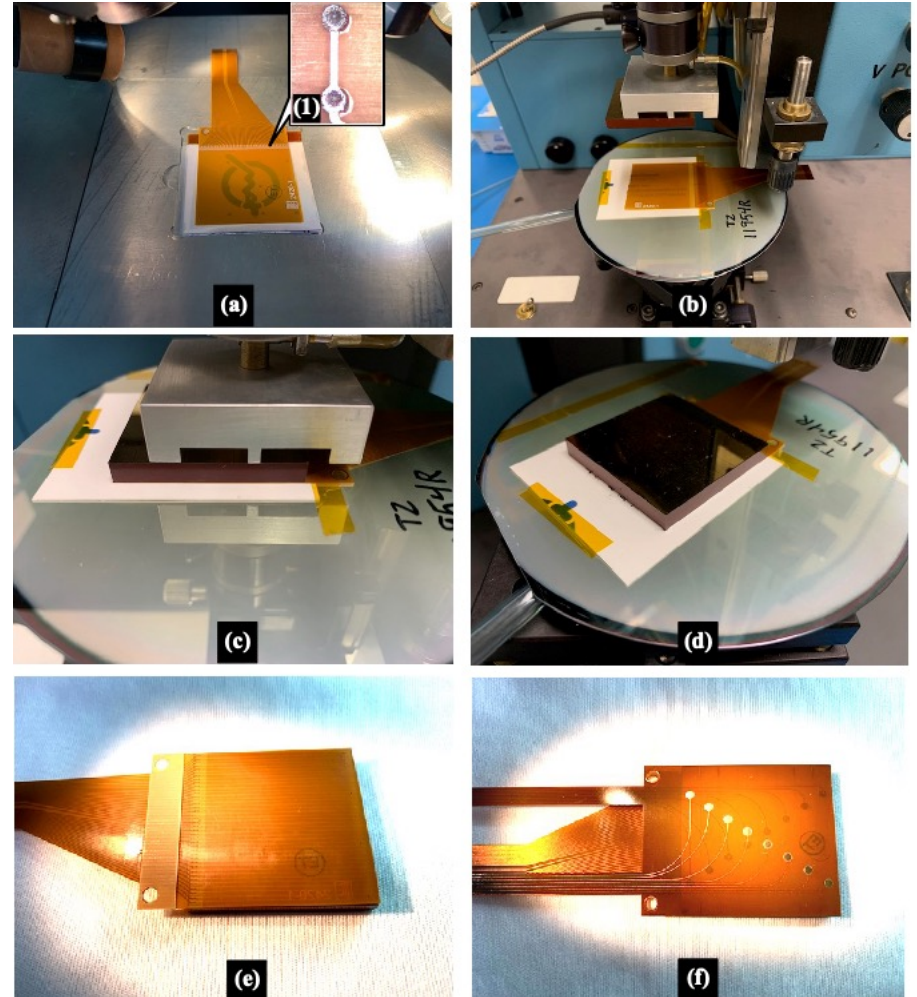
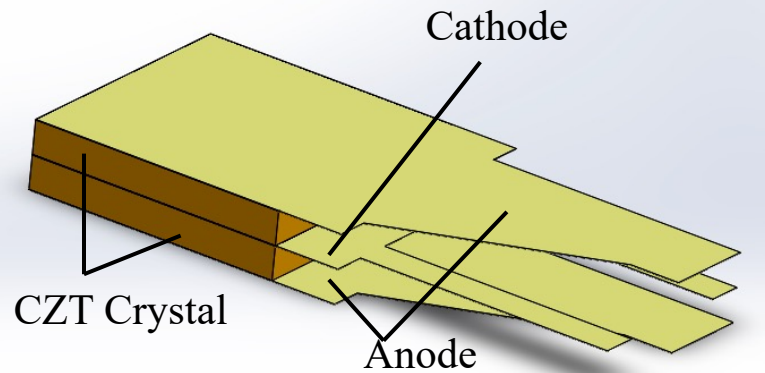


Flexible Circuit Design



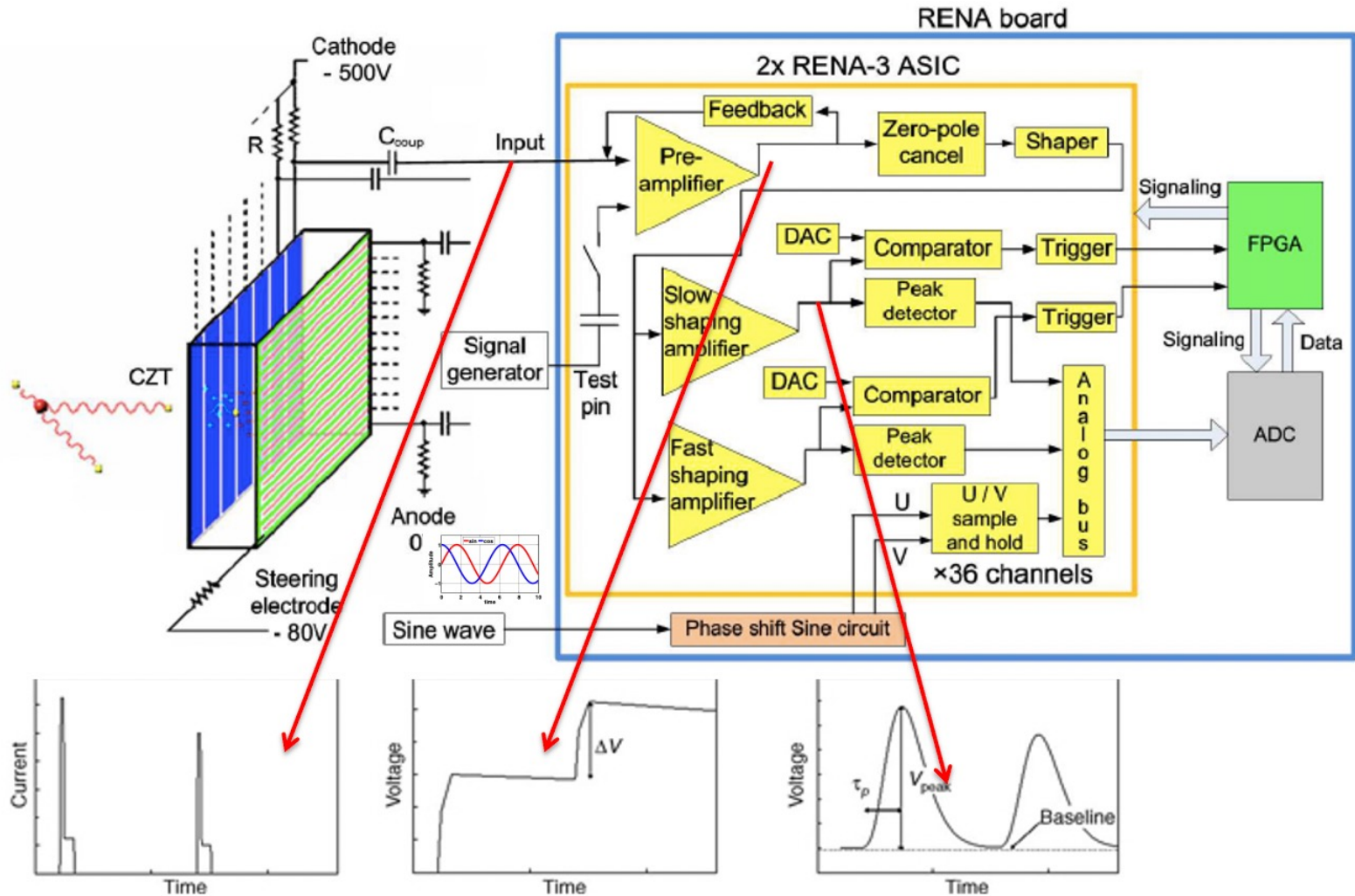
CZT Crystal Pair and Bonding

CZT Crystal Pair

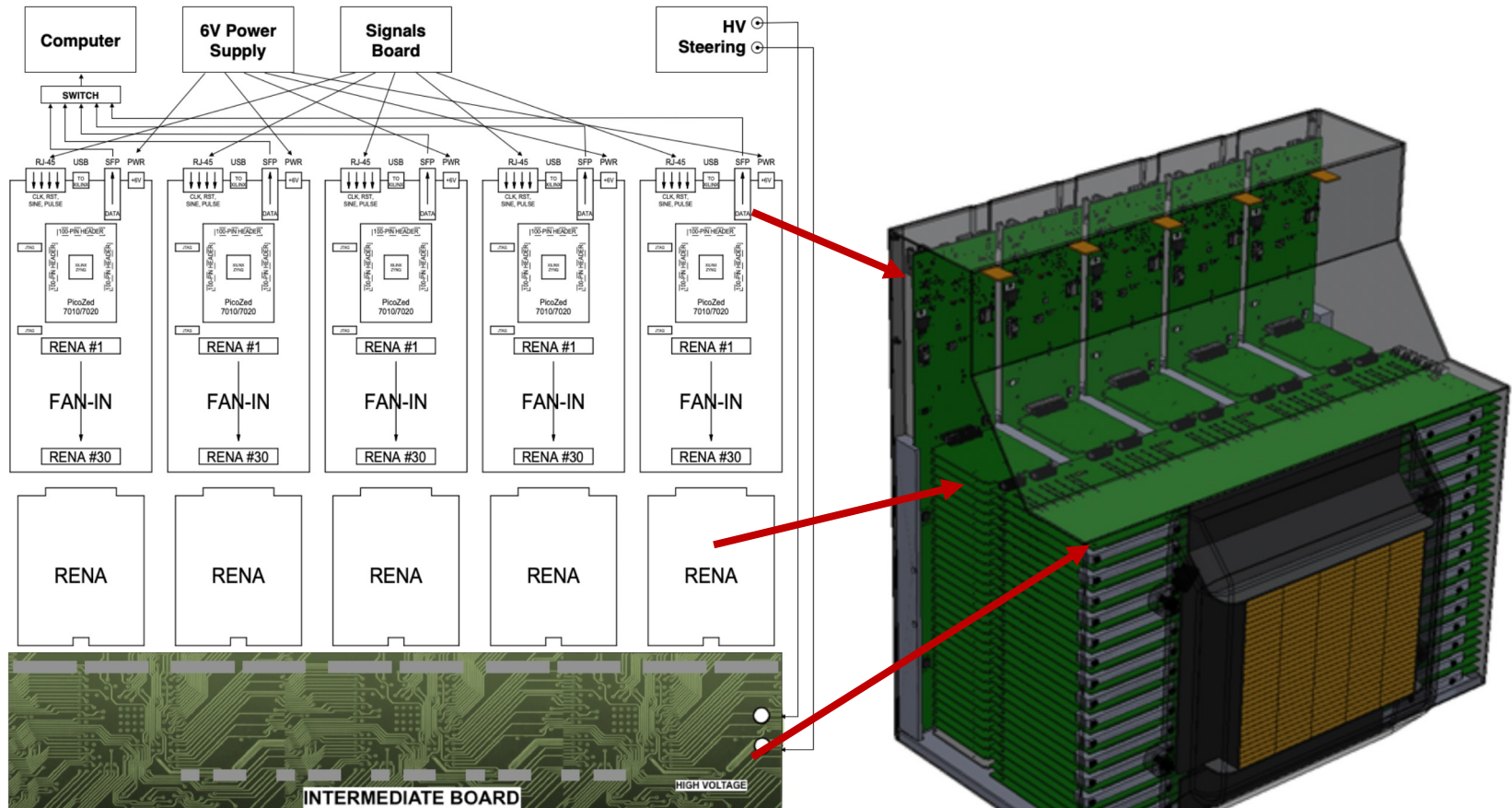


Collaboration with James Clayton
Polymer Assembly Technology, Inc. 9

RENA-3 ASIC



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.

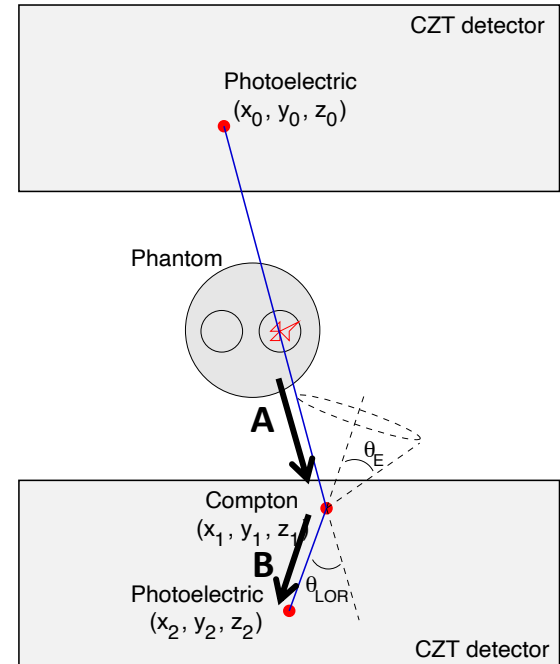
$$\theta_{LOR} = \cos^{-1} \left(\frac{\mathbf{A} \cdot \mathbf{B}}{|\mathbf{A} \cdot \mathbf{B}|} \right)$$

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

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

scattered
photon
energy

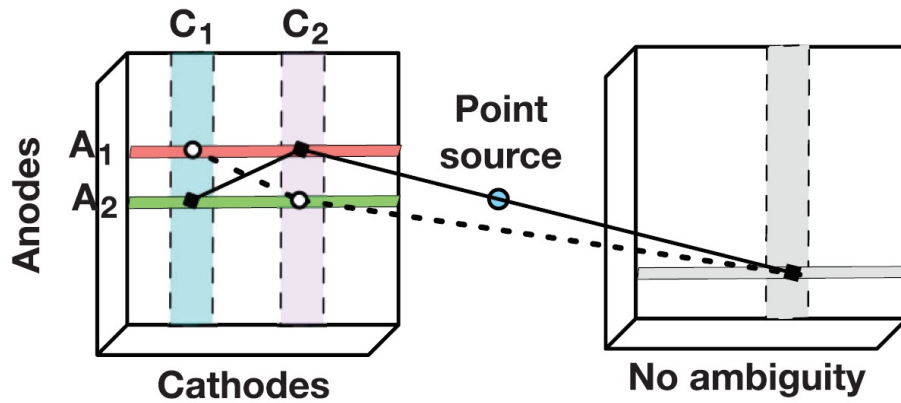
Incident
photon
energy



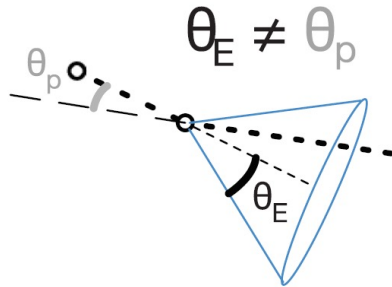
Idea: Interactions with large θ_{err} are likely not from the same event, therefore use a threshold cutoff for True/Random events

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

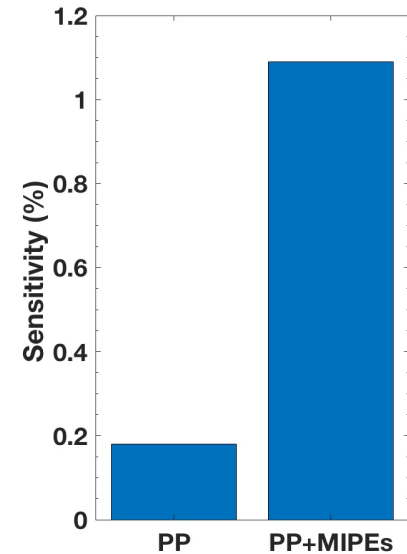
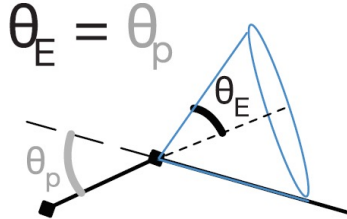
Increasing Sensitivity



Interaction set 1 (○)



Interaction set 2 (◆)

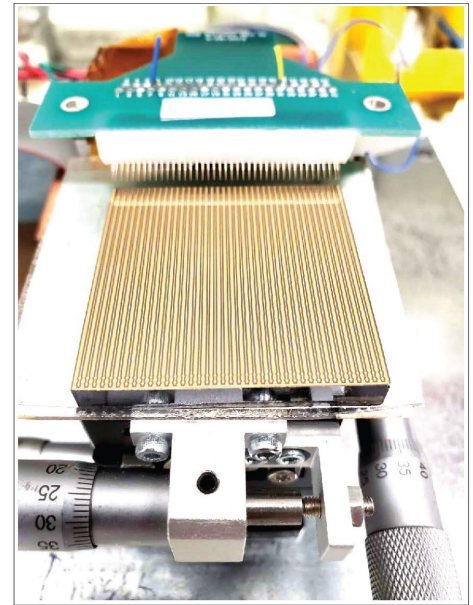


N. Nasir and S. Abbaszadeh, SPIE Medical Imaging, v.11596, pp .1011-1018 (2020)

E. Nikolakakis and S. Abbaszadeh, 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%

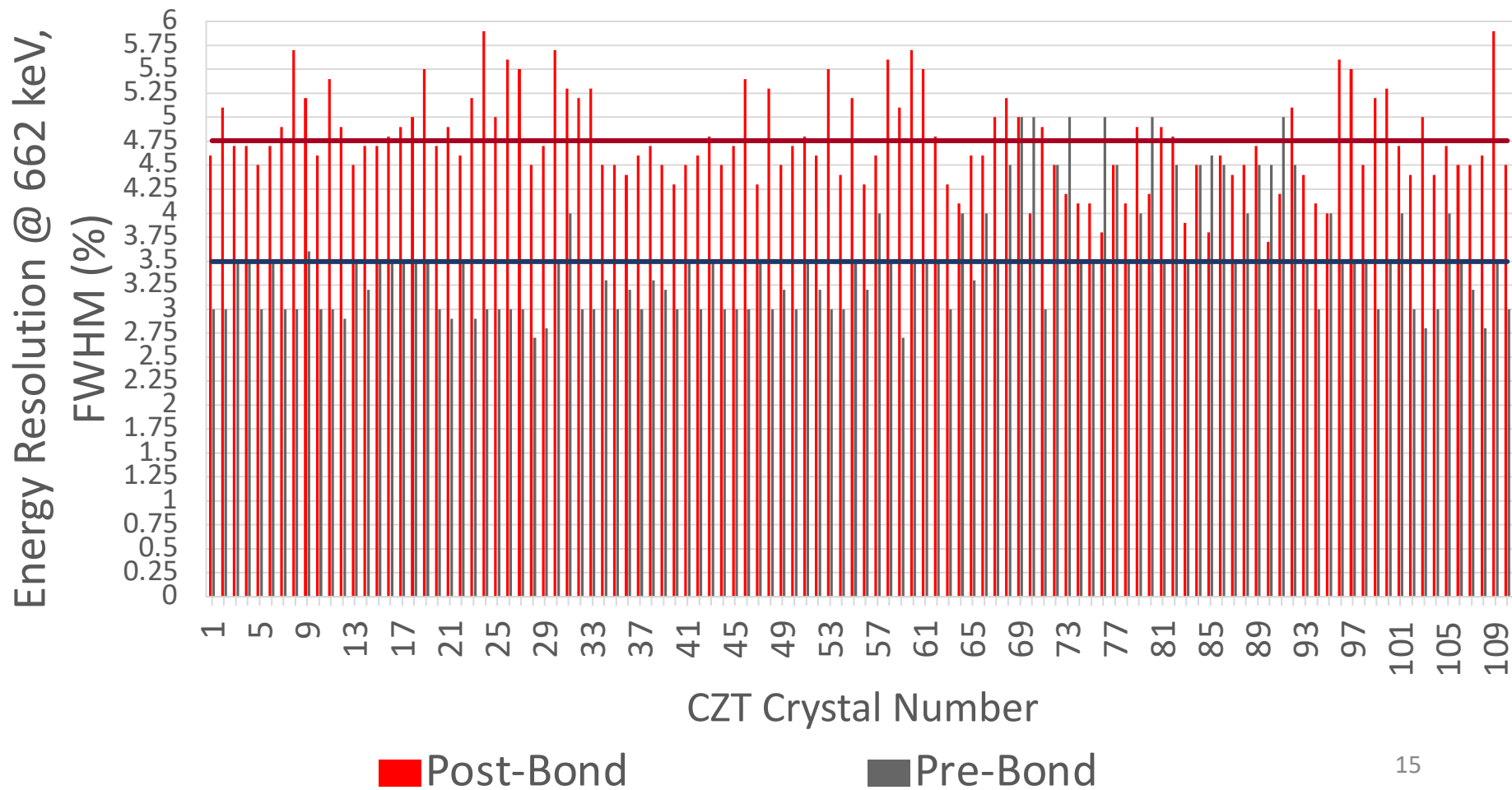


(a)

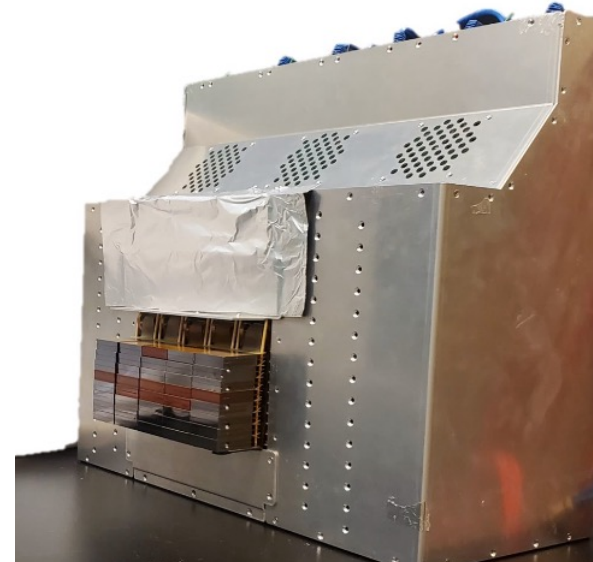
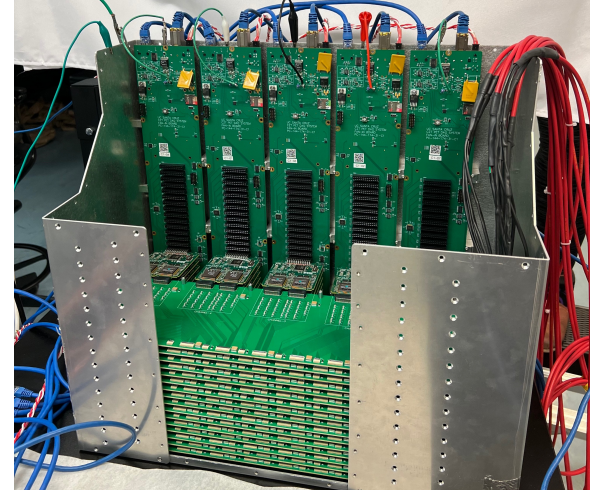
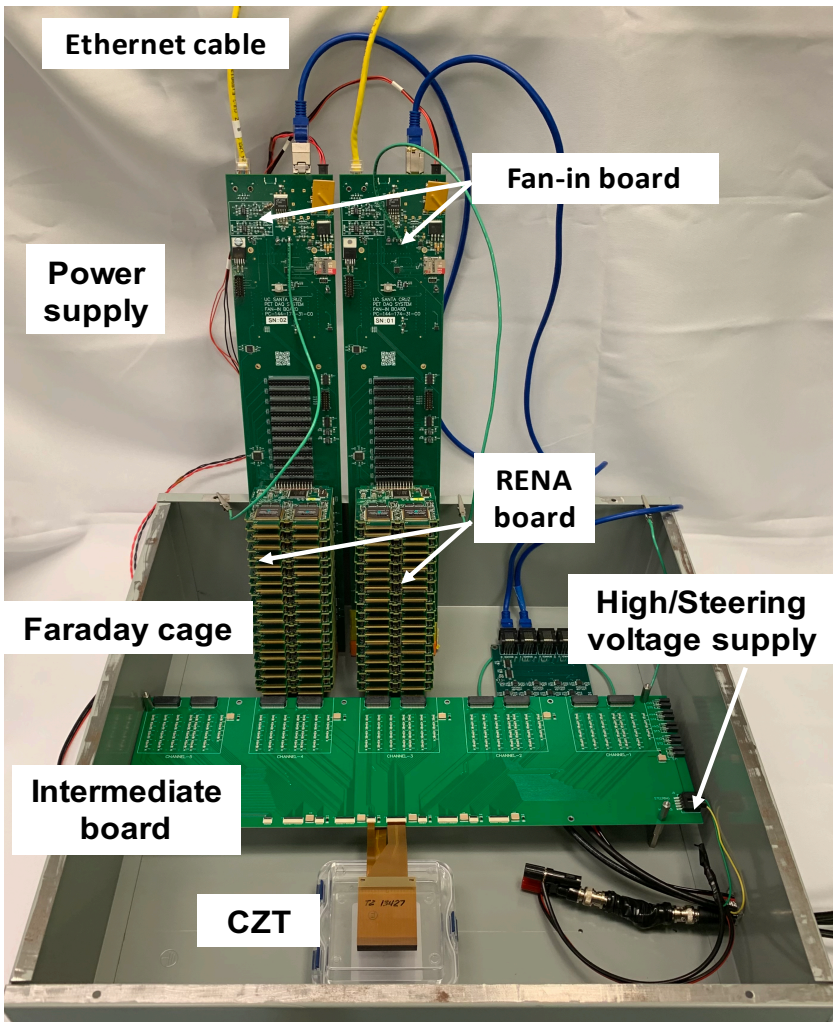


(b)

Energy Resolution of 110 CZT Crystals



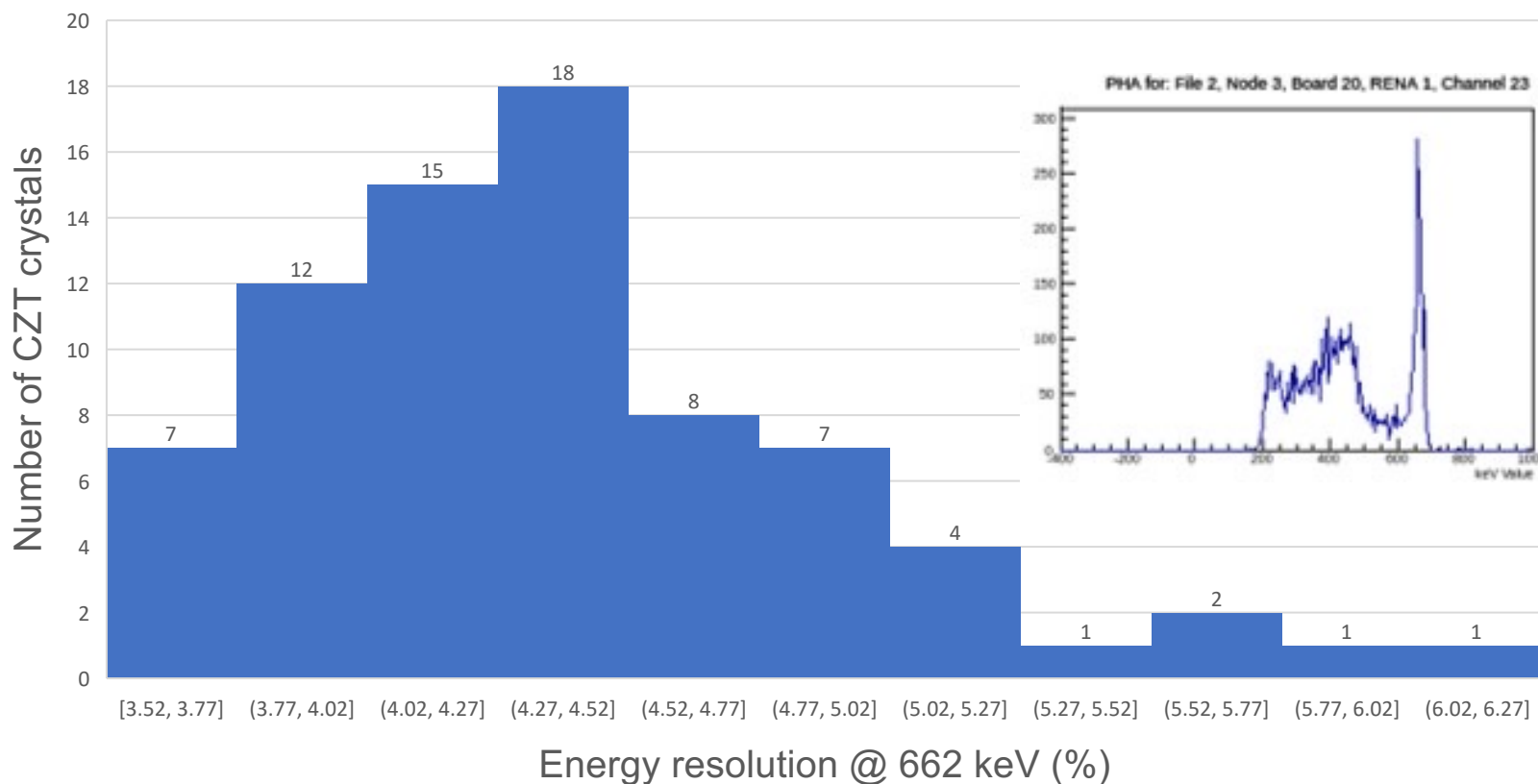
PET System Scale-Up Panel 1



Energy Resolution for Panel 1 Scale-Up

Without depth dependent correction

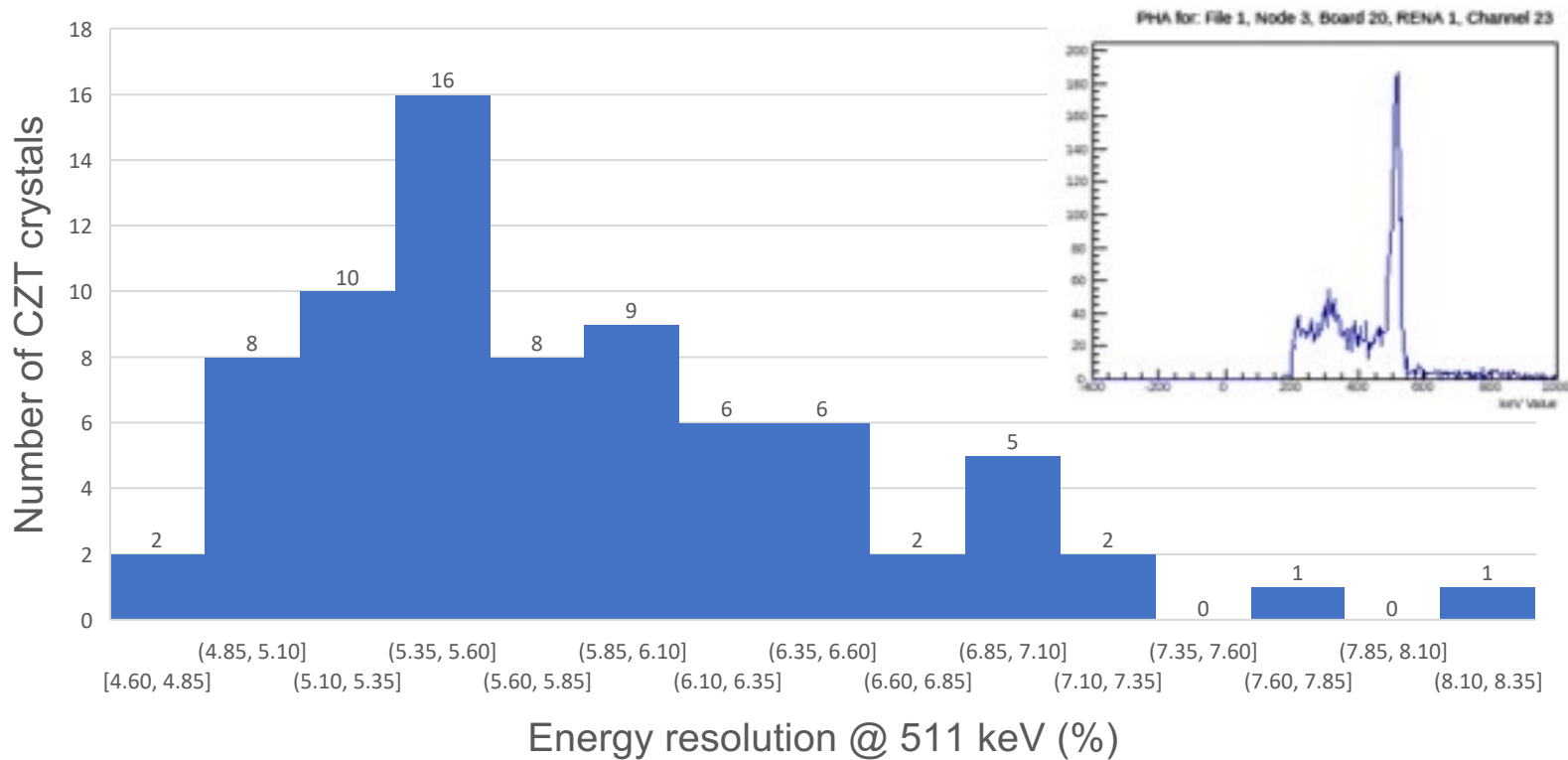
Avg: 4.40%
Std dev: 1.09%



Energy Resolution for Panel 1 Scale-Up

Without depth dependent correction

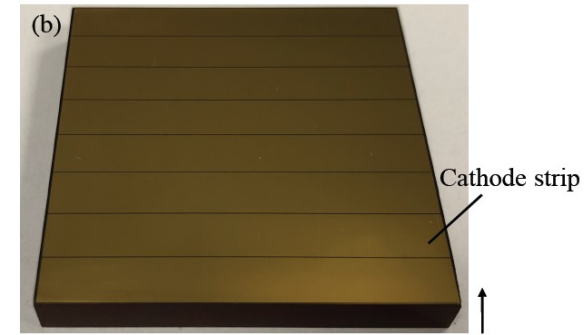
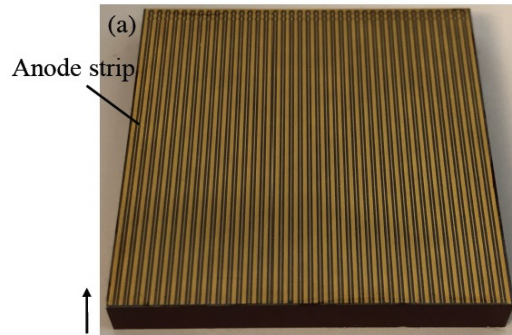
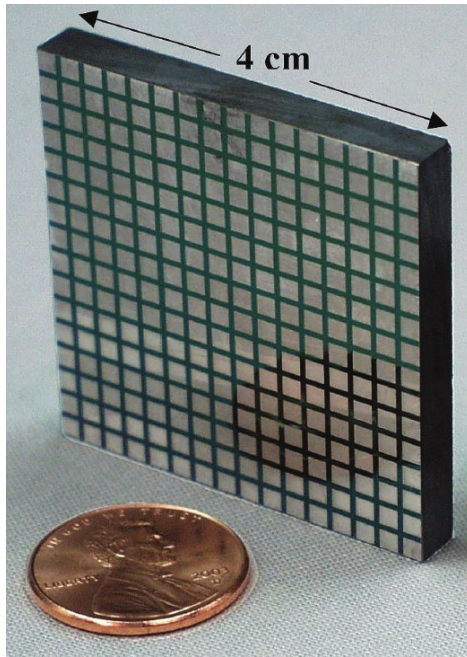
Avg: 5.85%
Std dev: 1.46%



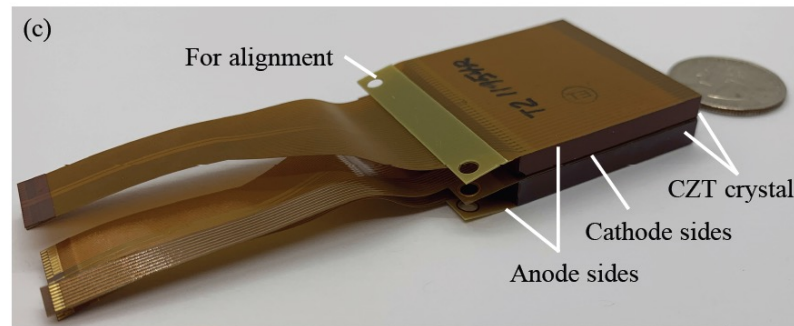
Conclusion

- 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



Direction of photon entry



Direction of photon entry