3-D Position-Sensitive CdZnTe γ-Ray Spectrometers

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Acknowledgements
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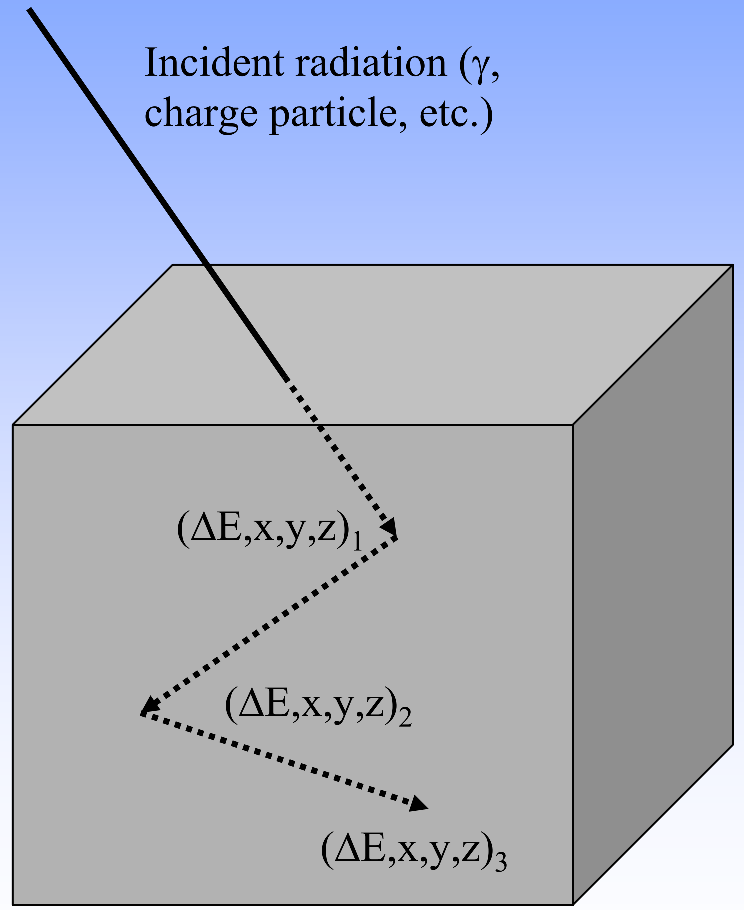
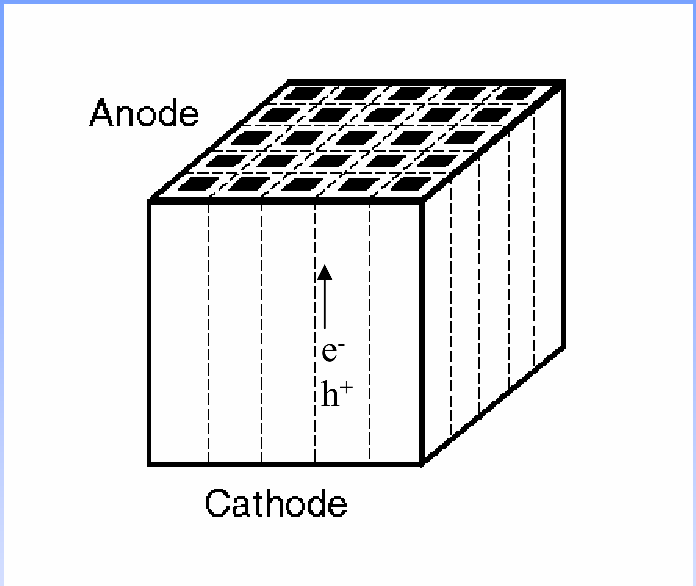
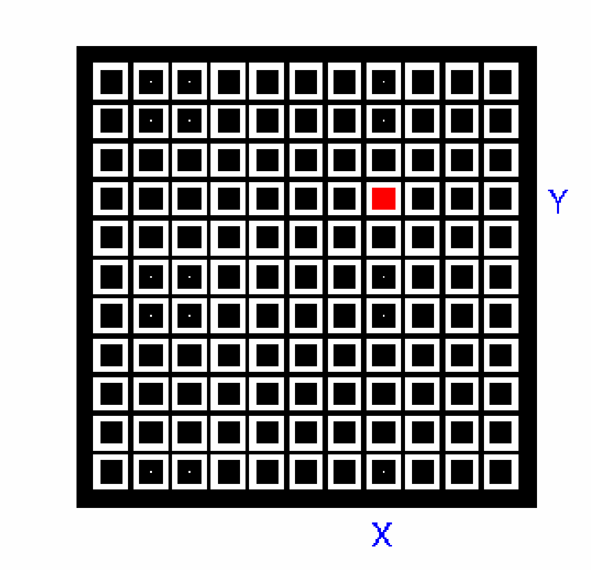
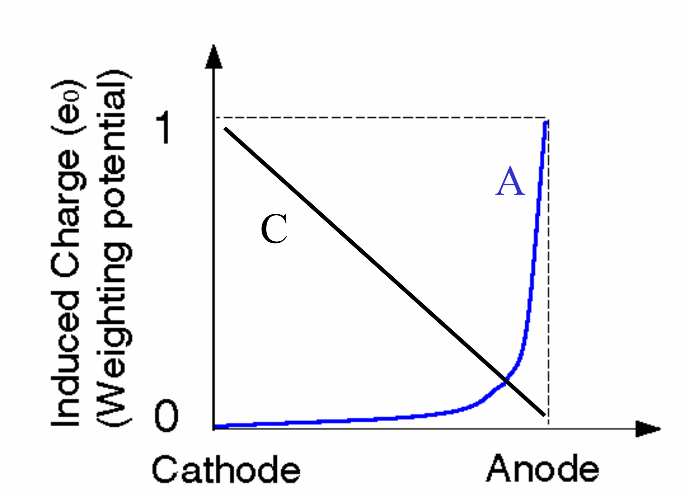
What is a 3-dimensional position-sensitive semiconductor detector?



Principle of Operation







From pixel #i : (E', x, y)

Depth $z = C/A = C/E'$

$(E', z)_i \Rightarrow E_0$ (True E)

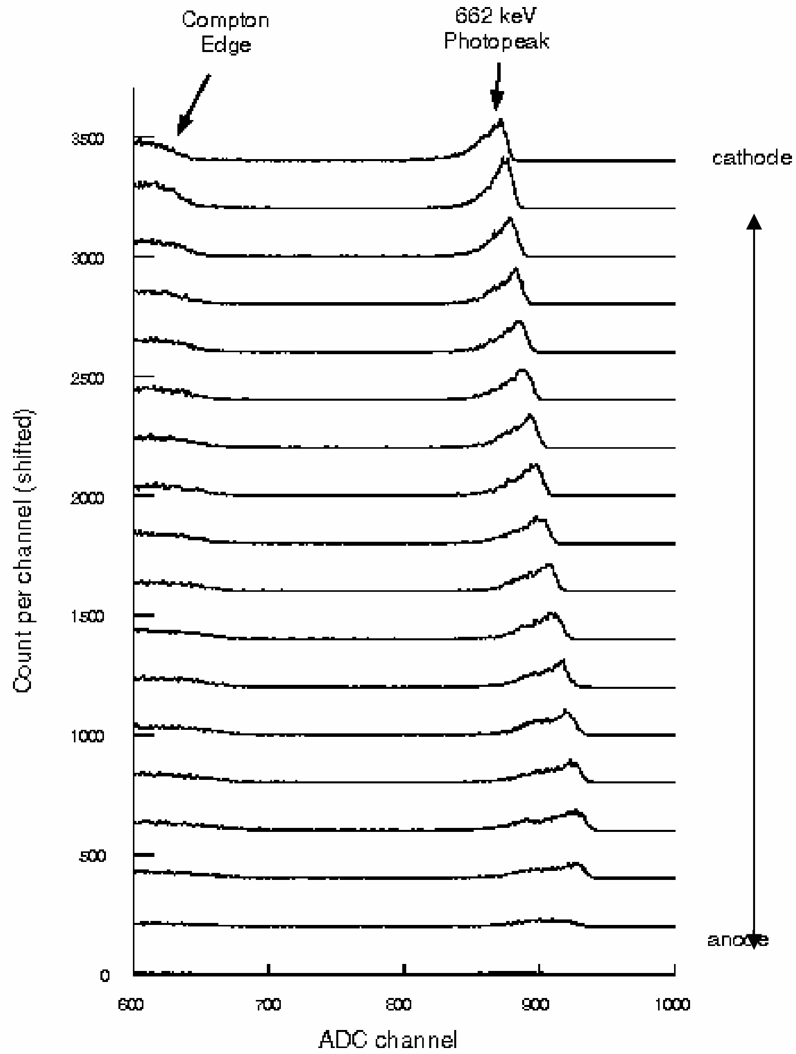
$$\Downarrow$$

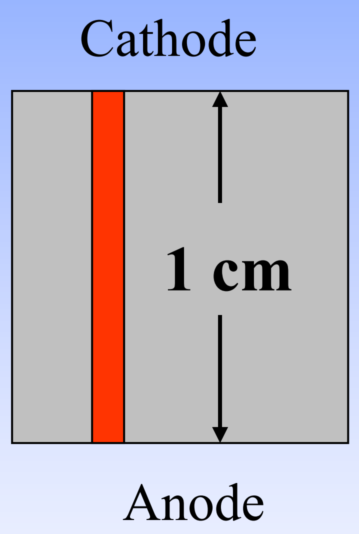
$$(E_0, x, y, z)$$

Advantageous of 3-D detectors

- Single polarity charge sensing → Overcome the effects of severe hole trapping
- Depth sensing → Correct electron trapping
- 3-D coordinates of interactions → Mitigate the effects of material non-uniformity to the scale of position resolution (~ 1mm)
- Minimum electronic noise (leakage current & detector capacitance are shared between pixels)
- γ-ray imaging
- Detector physics (increase sensitivity by recognizing signatures of radiation interactions)

The effect of electron trapping

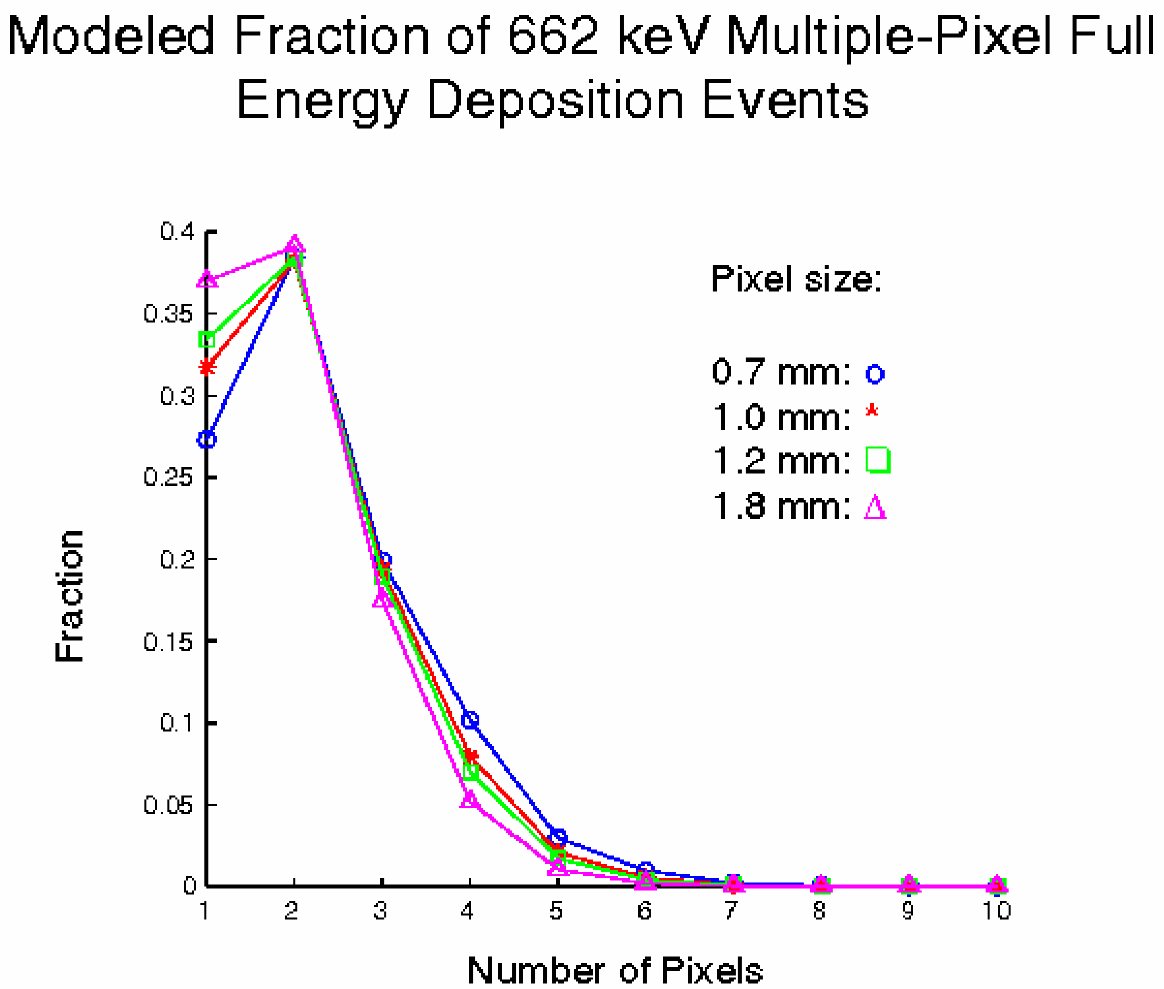




There are virtually ~**2400** voxel detectors on each device.

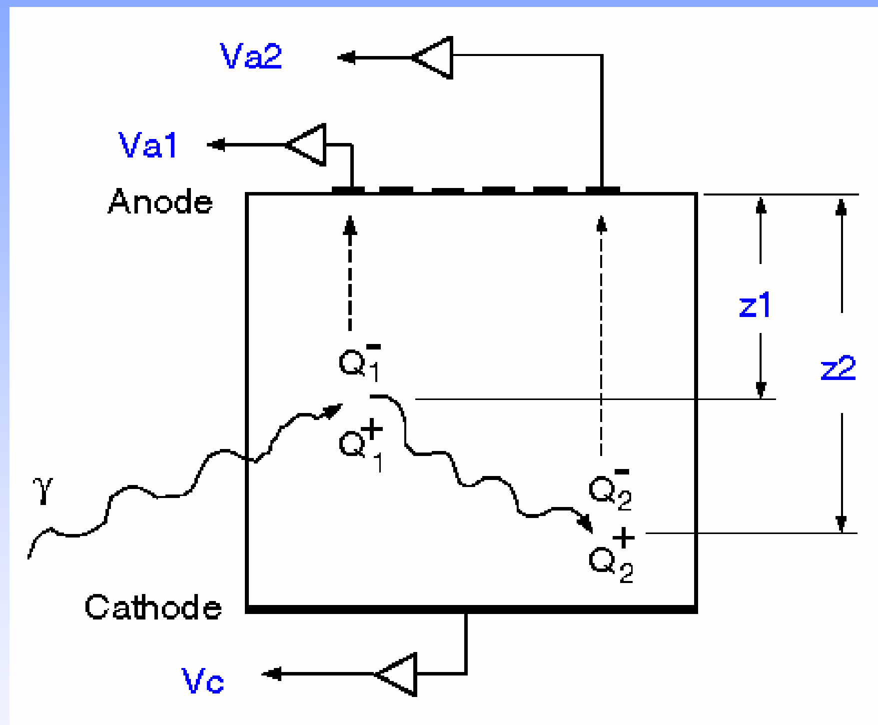
Results of first-generation detectors (1 cm^3) were reported during 1998-2001

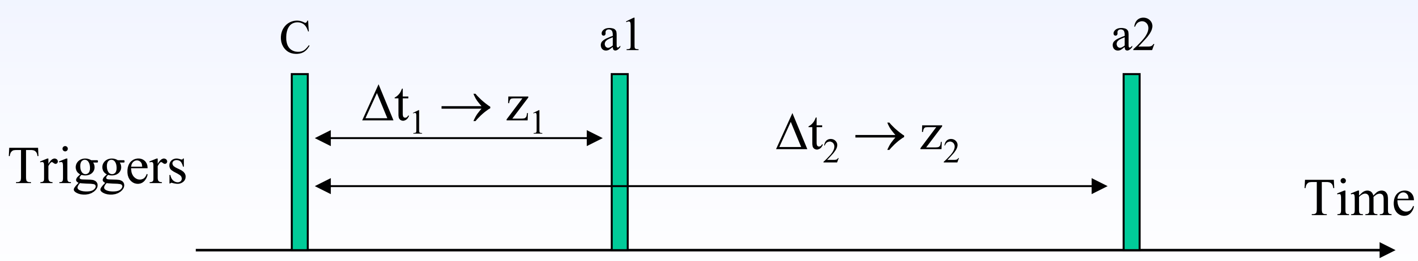
Importance of multiple interaction events



The size of electron cloud was considered

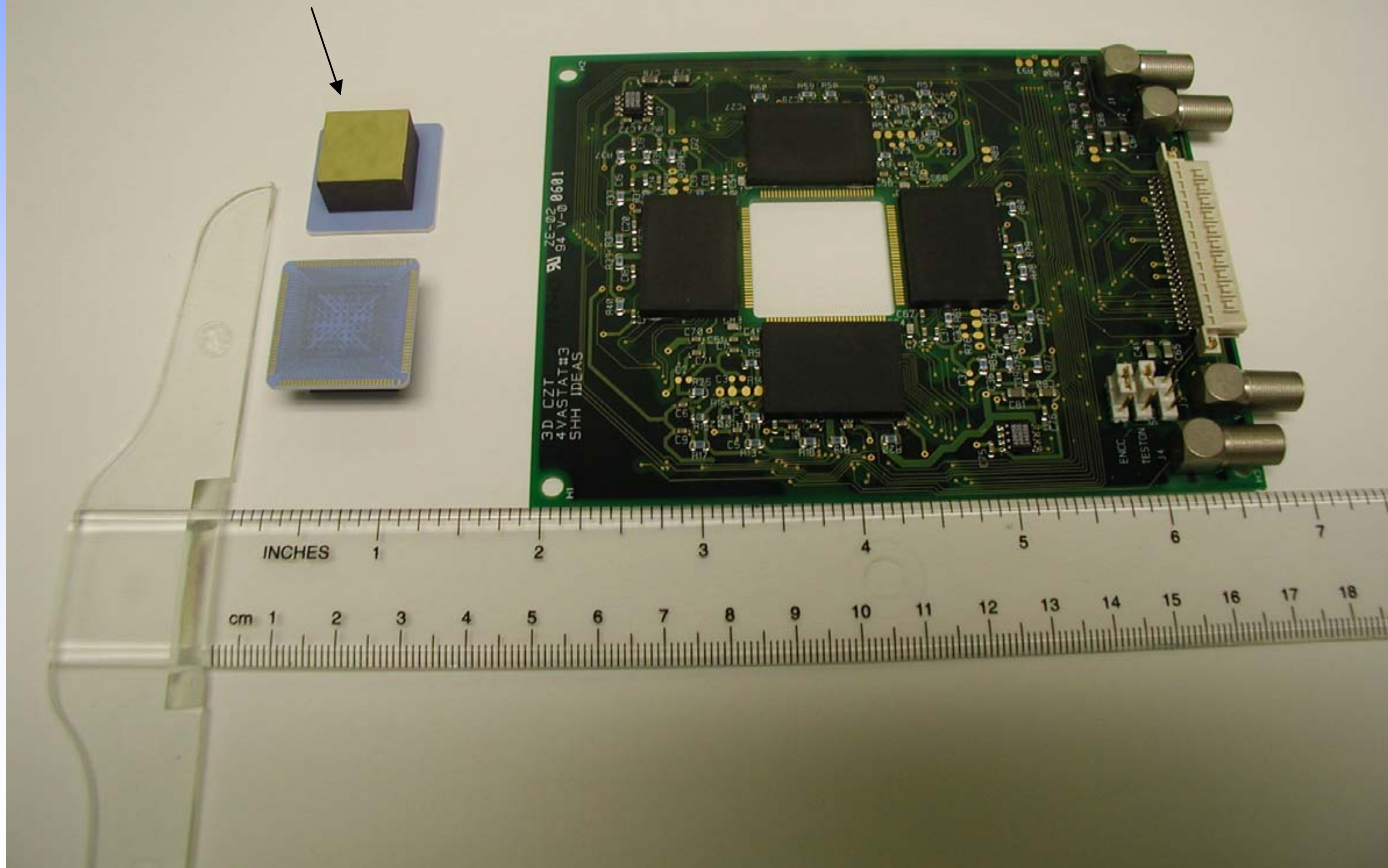
Second-generation 3-D CdZnTe detectors can provide $(E,x,y,z)_i$ of multiple γ-ray interactions



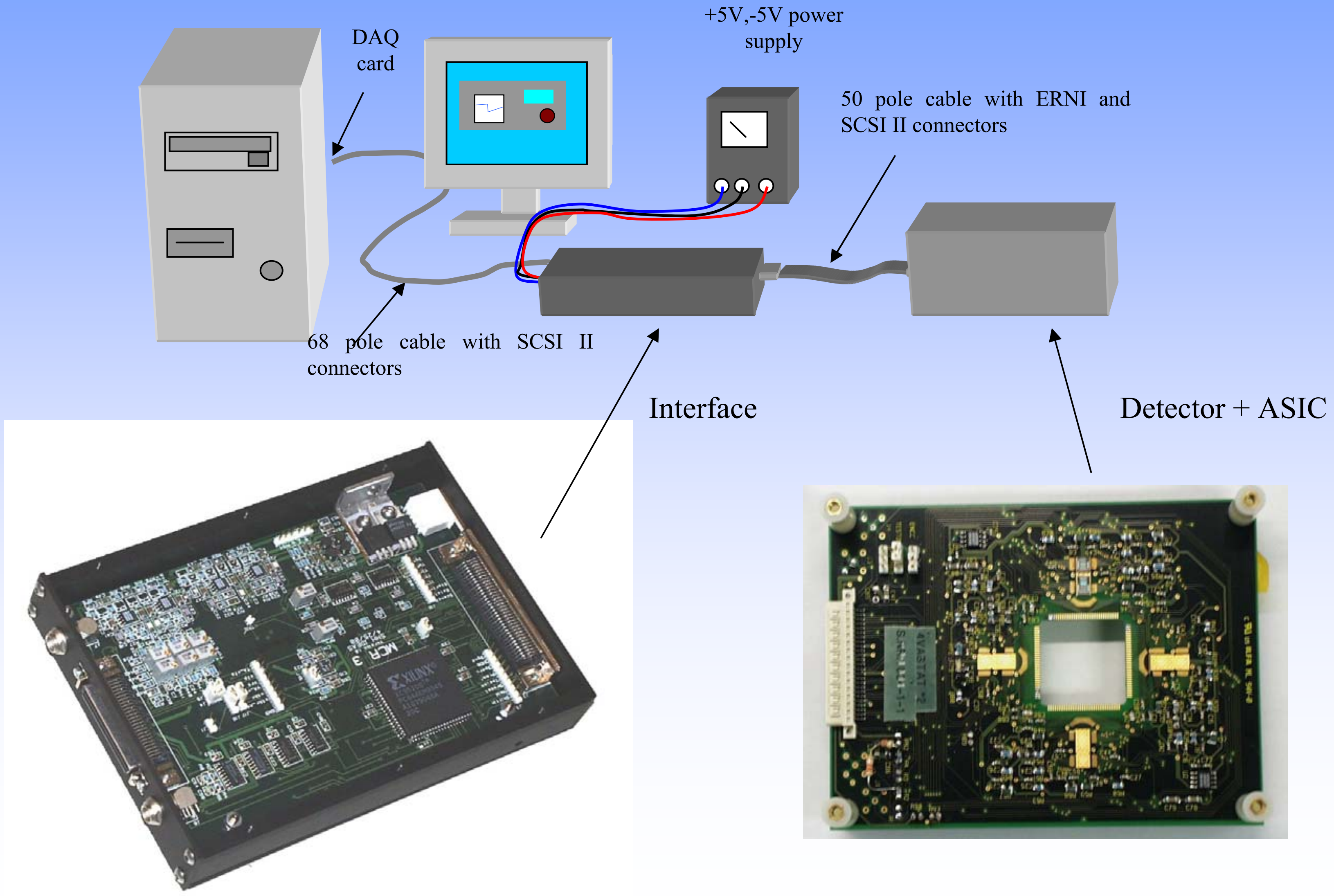


Detector front-end

1.5×1.5×1 cm CdZnTe (**Four** from eV Products)

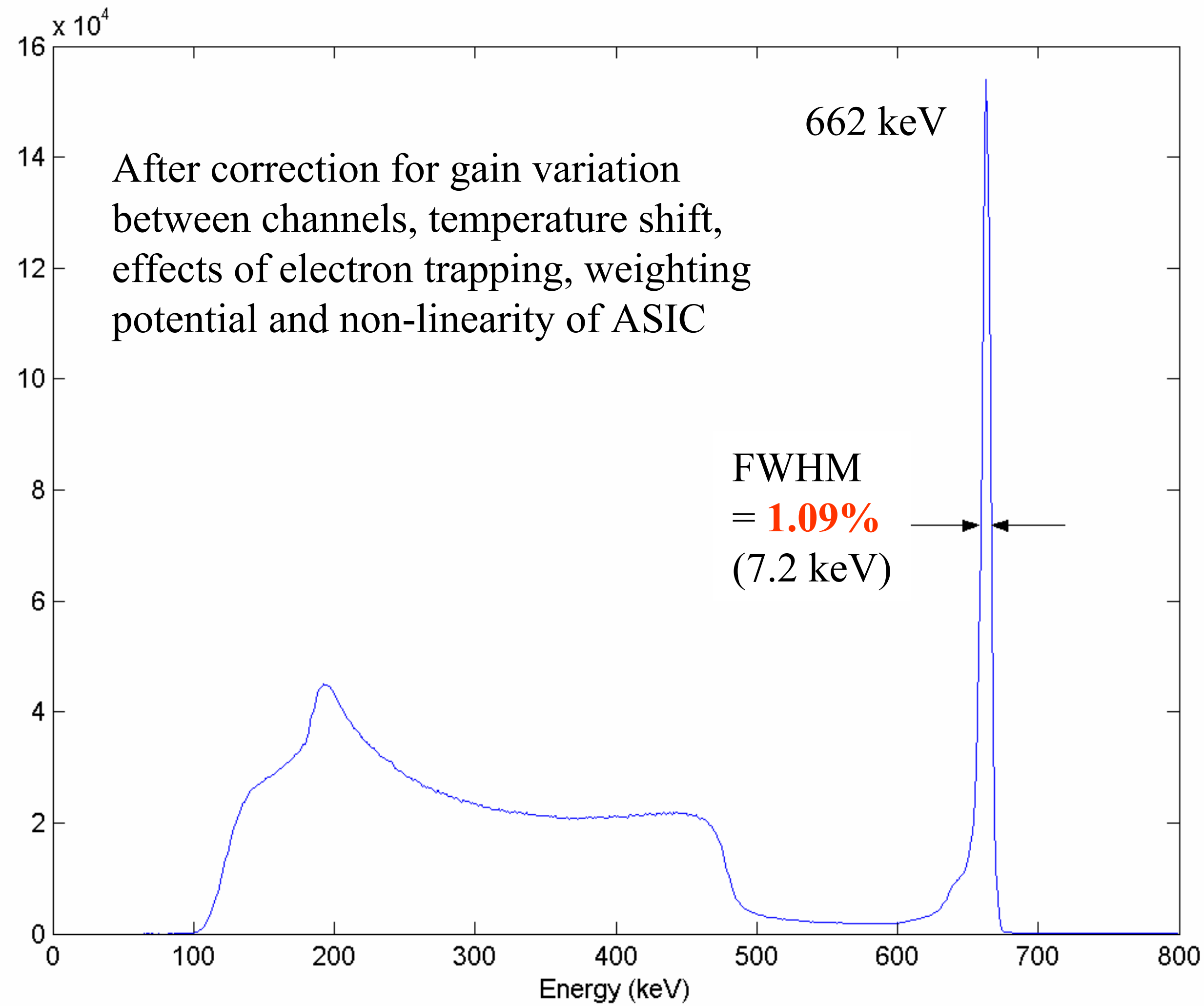


Detector system



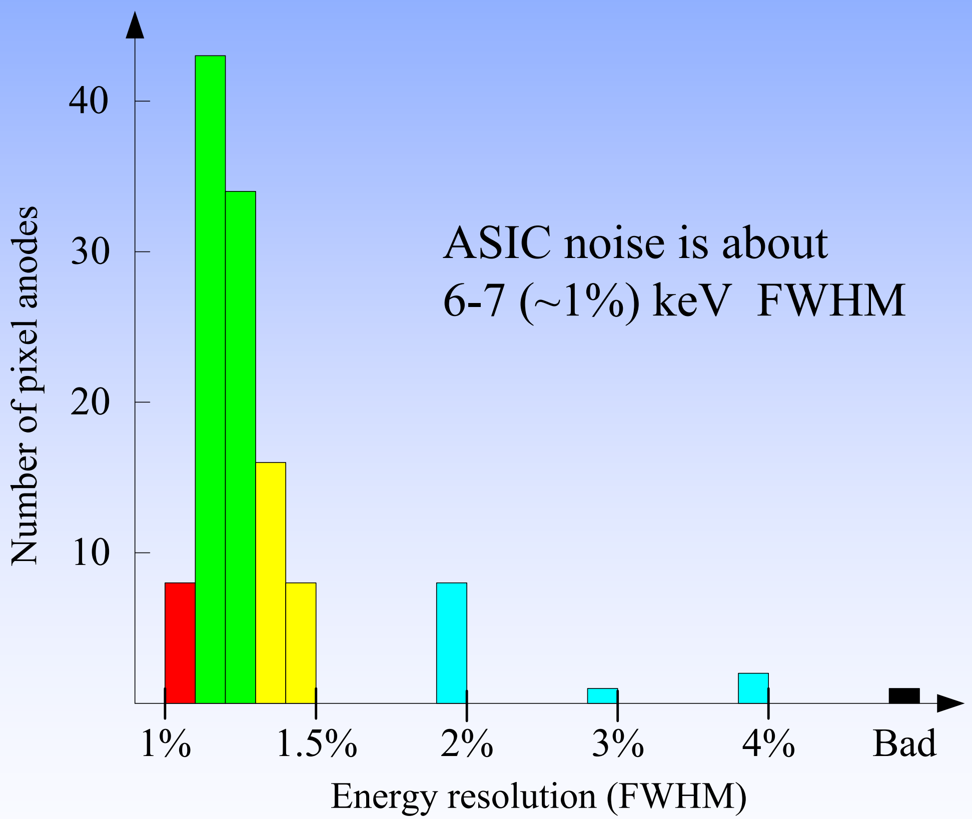
Energy spectrum of ^{137}Cs from one-pixel events

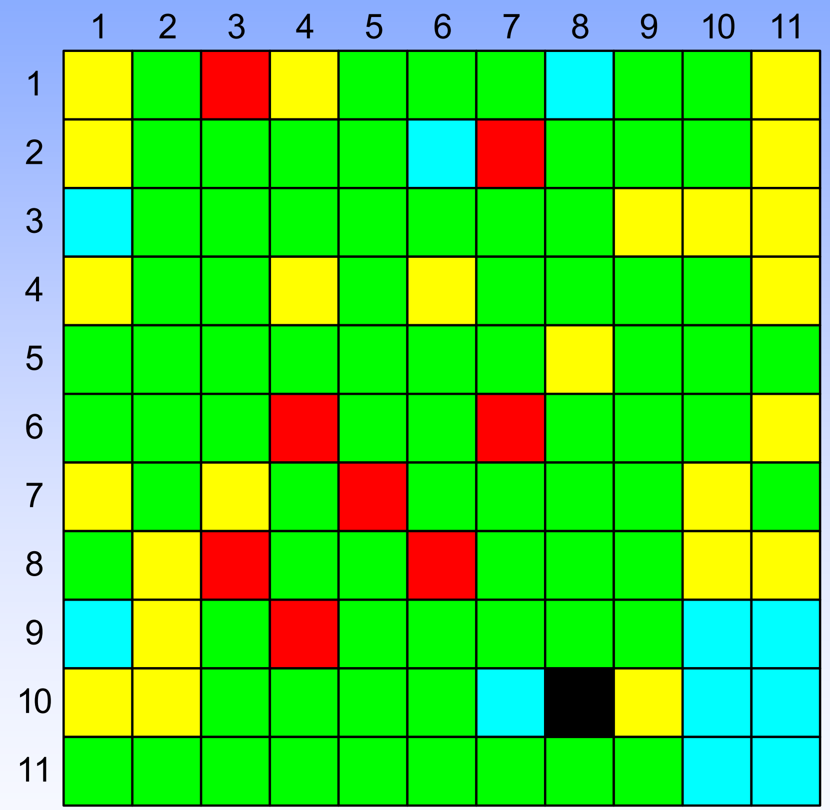
Detector # **2.3** (**120** working pixels): V_C = - 2000 V; V_{A-G} = 80 V



Distribution of energy resolutions (one-pixel events)

Detector # **2.2** (**120** working pixels): V_C = - 1400 V; V_{A-G} = 90 V; Time = **50 h**

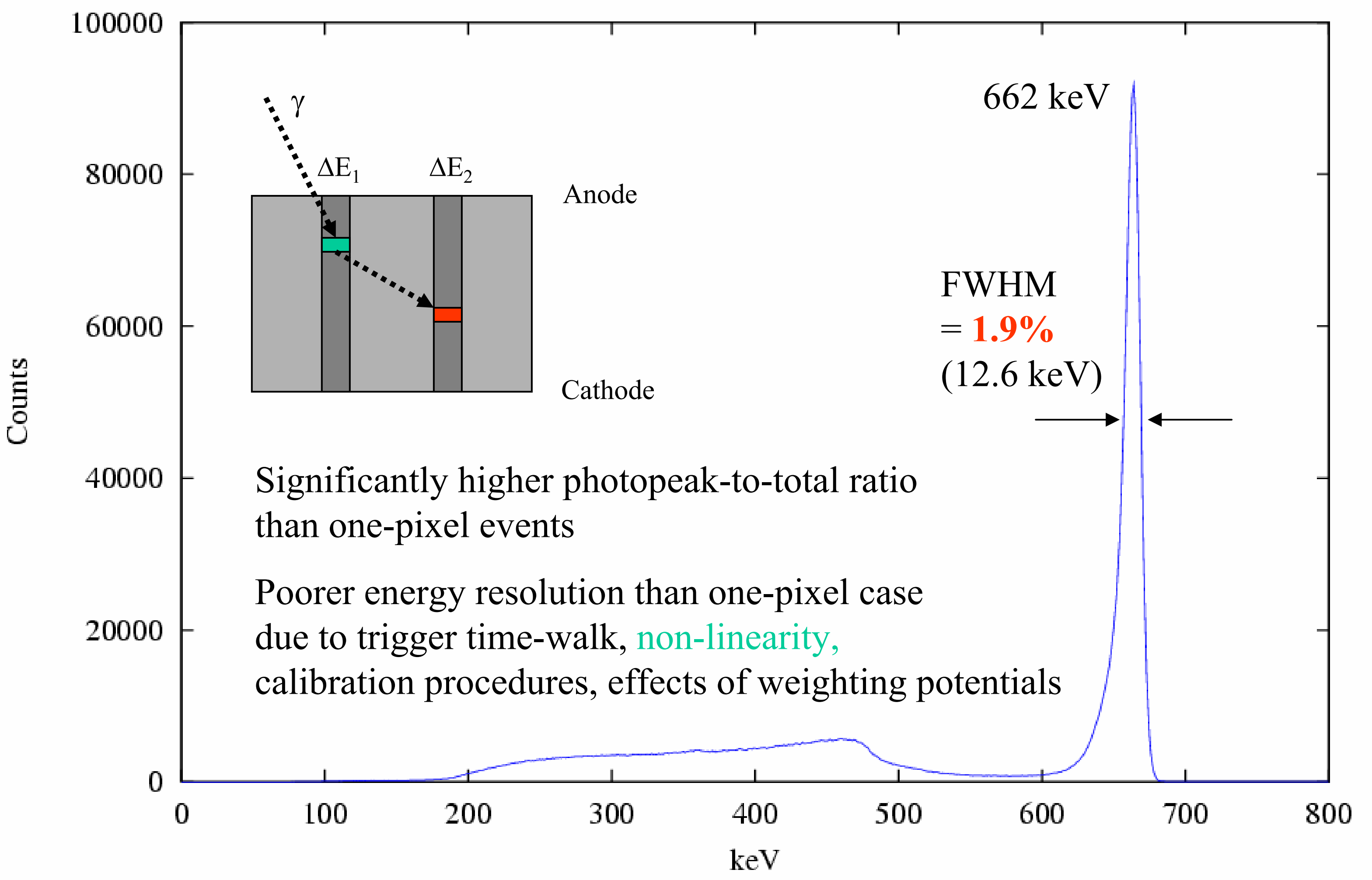




Energy resolution can be further improved if the ASIC noise can be reduced from 6-7 keV (~ 1%) to ~ 3 keV (0.5%) FWHM as planned

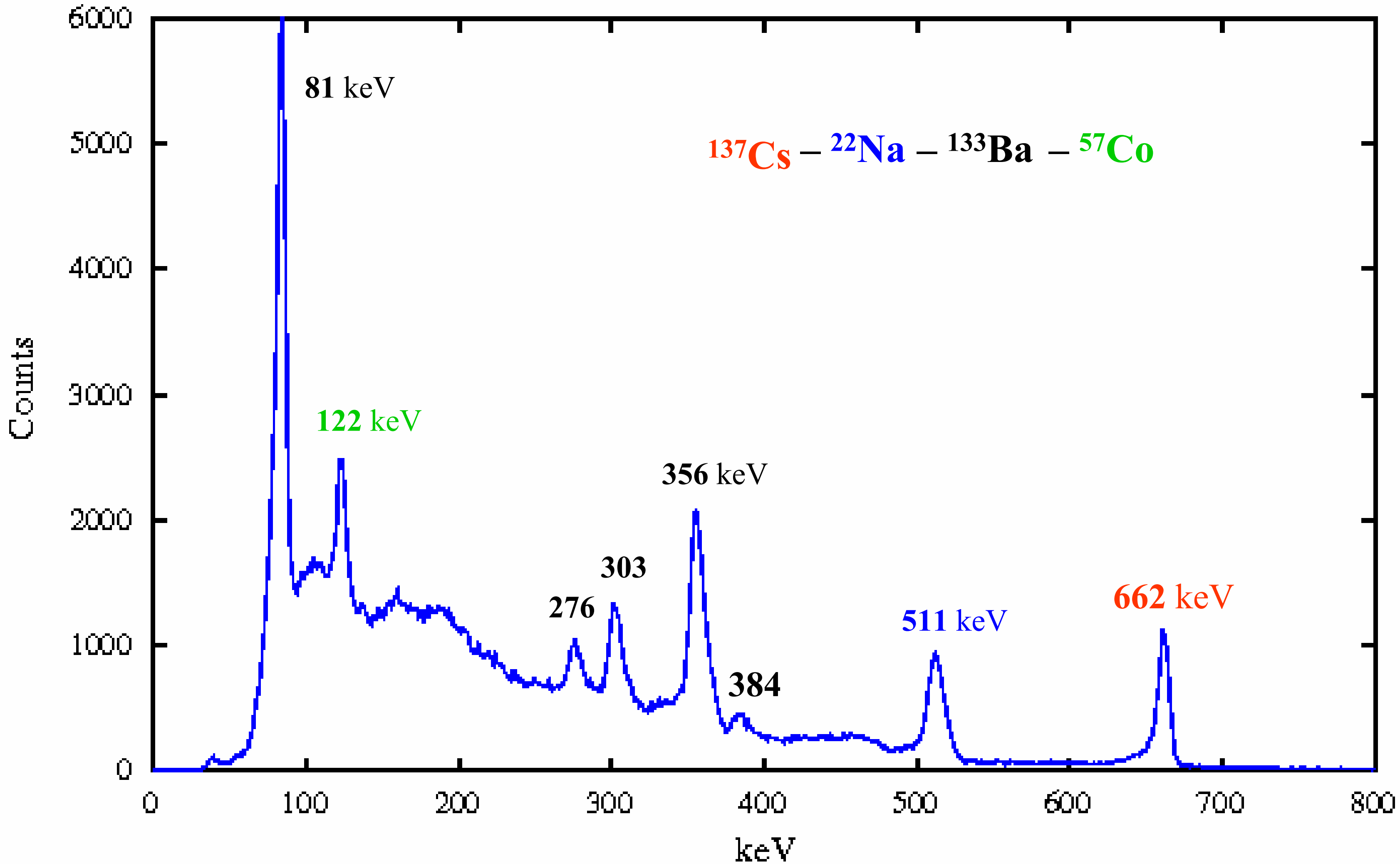
Energy spectra of ^{137}Cs from two-pixel events

Detector # **2.3**: V_C = - 2000 V; $V_{A\text{-}G}$ = 80 V; Time = **50 h**



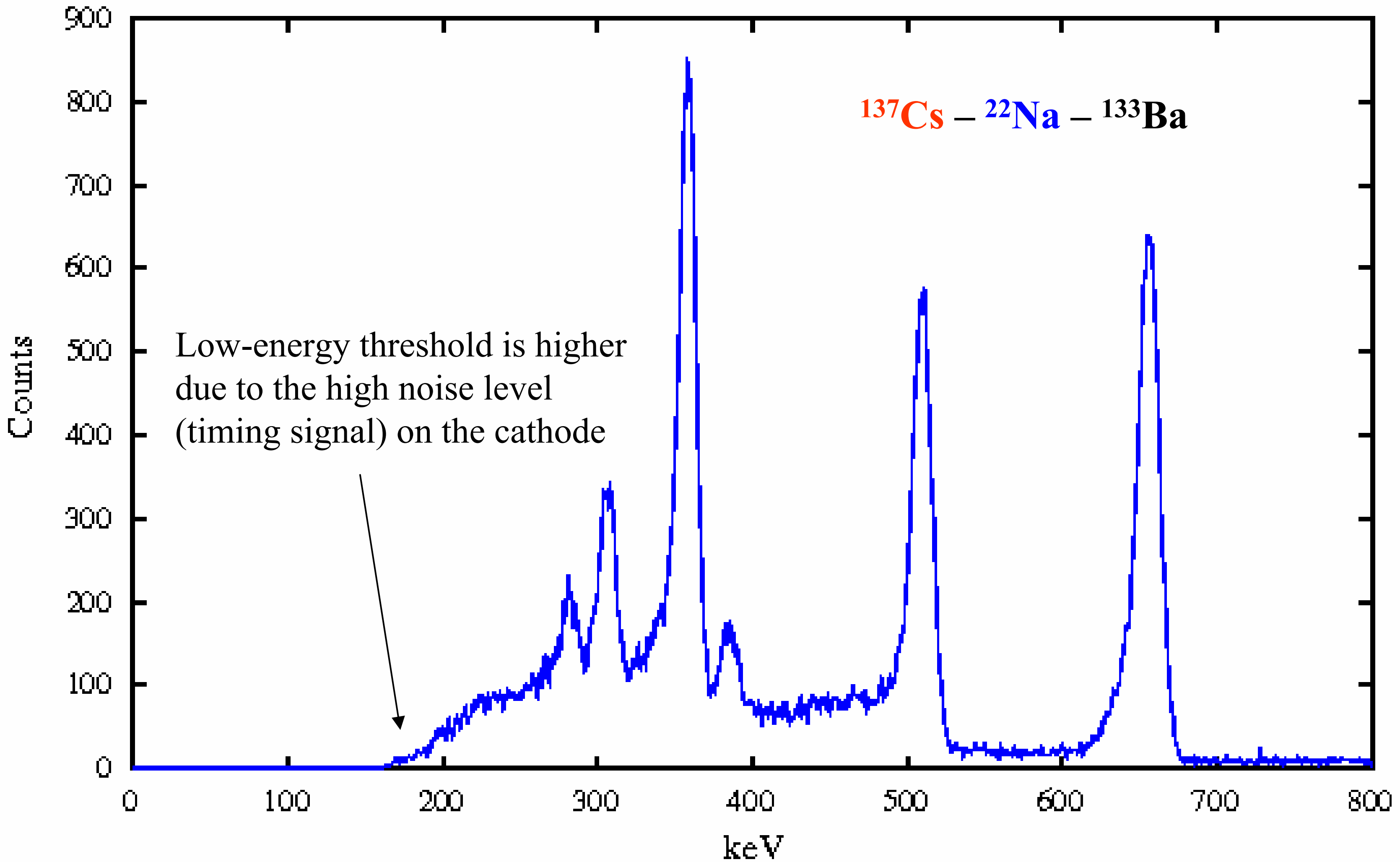
Measurement of multiple sources (one-pixel events)

Detector # **2.2** (**120** working pixels): V_C = - 1400 V; $V_{A\text{-}G}$ = 90 V; Time = **1 h**

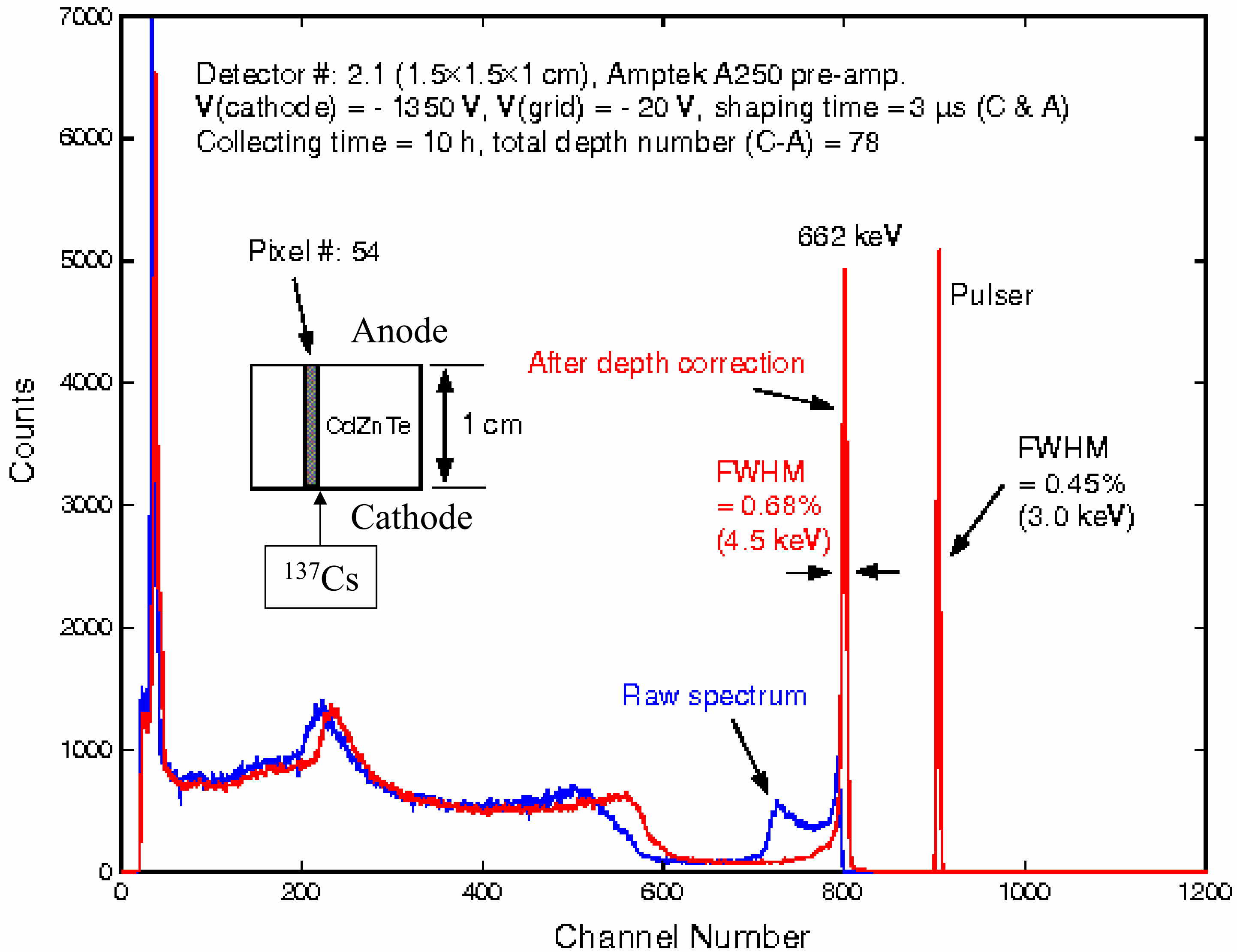


Measurement of multiple sources (two-pixel events)

Detector # **2.2** (**120** working pixels): V_C = - 1400 V; $V_{A\text{-}G}$ = 90 V; Time = **1 h**



When ASIC noise is reduced to 3 keV FWHM



Summary on 3-D CdZnTe

- Energy resolution:

  1.1% FWHM at 662 keV for single-pixel events → (?)

  2.0% FWHM for two-pixel events → ?

- Position resolution in 3-D:

  1.2 mm in X-Y and ~ 0.5 mm in Z at 662 keV

- Energy depositions and 3-D positions of multiple-interactions are fully readout using ASIC for the **first** time.

- Current development:

  Improvement on ASIC (Testing 3rd design iteration ASICs)

  Larger detectors

  Miniaturize ASIC (for tile-able systems)

- Detector operation can be **simple** for end users

3-Dimensional Position-Sensitive HgI_2 γ-Ray Spectrometers

Zhong He and James E. Baciak

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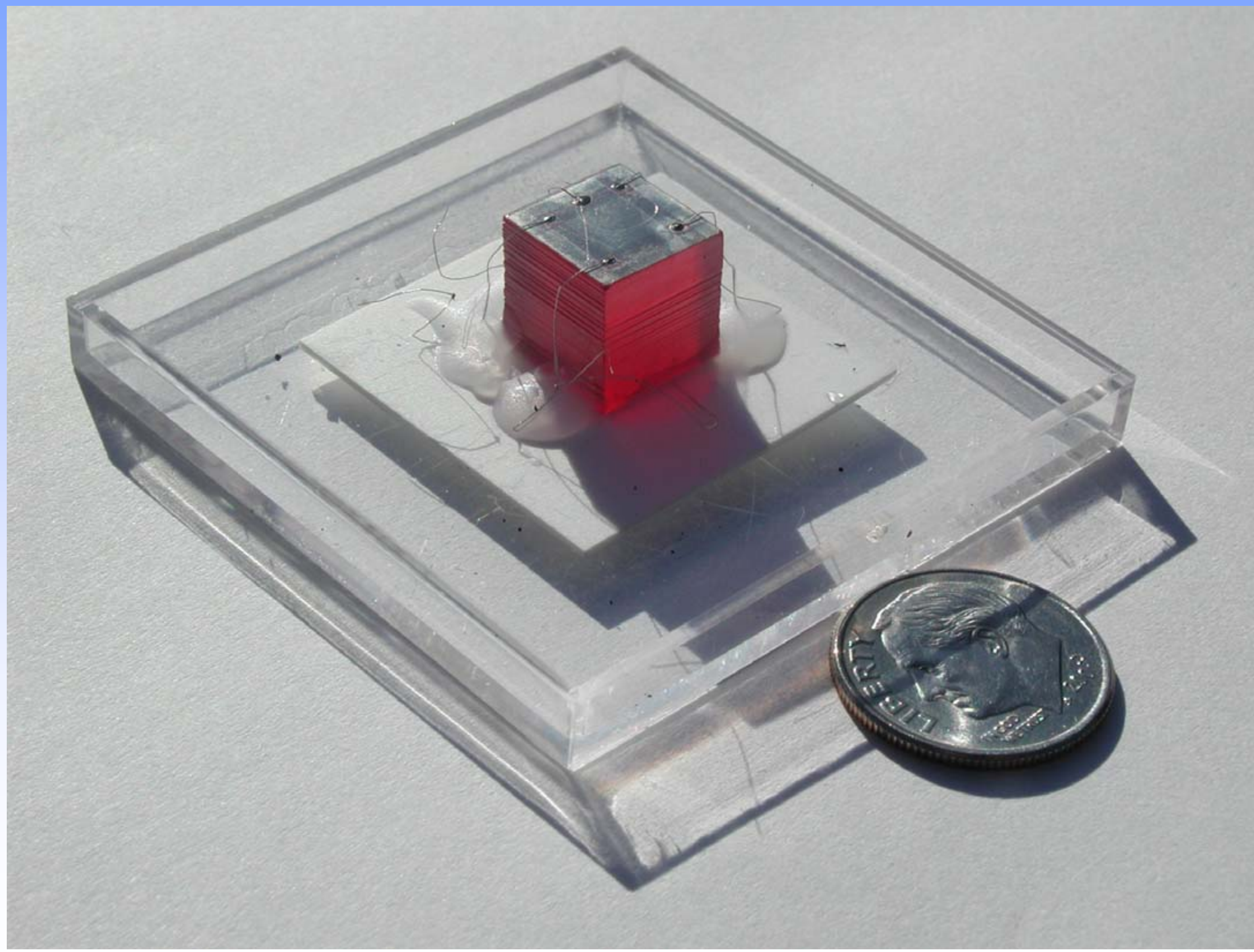
Constellation Technology Corporation
and NASA STTR program

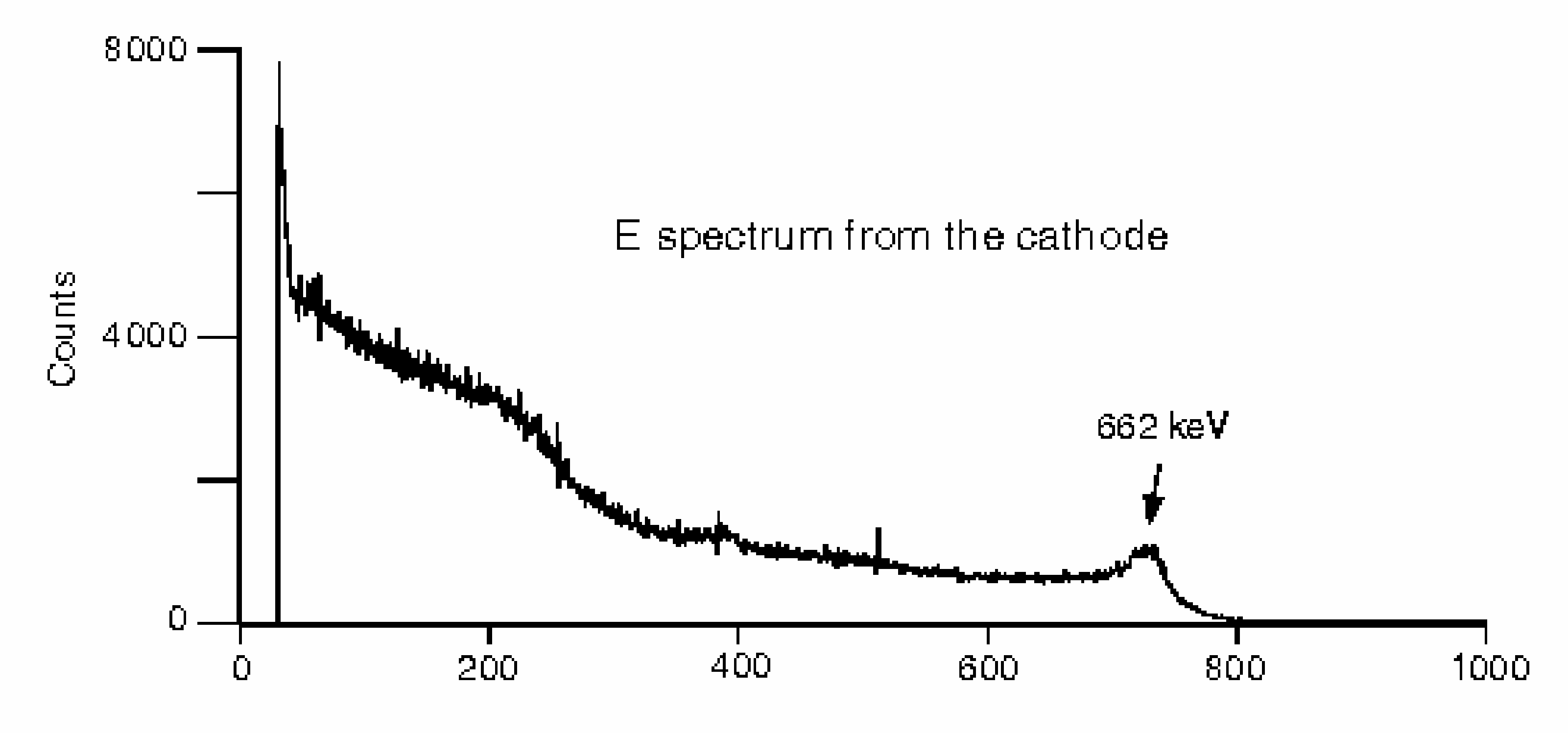
Facts on HgI_2

- Advantageous
  - high Z (80-53)
  - high density (6.4 g/cm^3)
    (1 cm $HgI_2 \approx$ 2-3 cm of CZT, more of Ge)
  - large band-gap (2.13 eV)
    (room-temperature operation)
- Challenges
  - very low hole mobility, severe hole trapping
  - low electron mobility
    (require higher bias ~1 kV/mm and long shaping time)

A sample 1cm thick HgI_2 Detector



If conventional readout technique is used

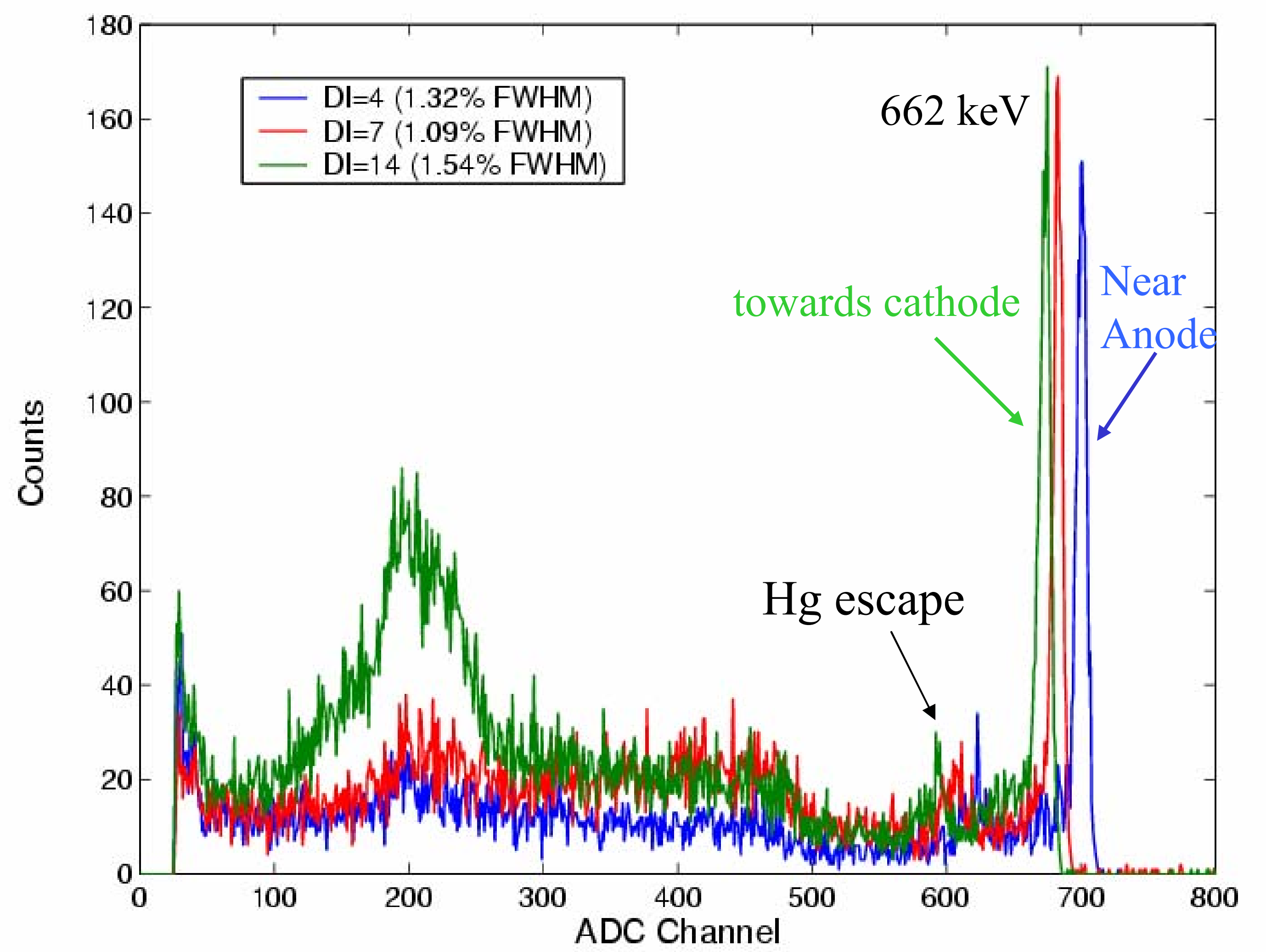


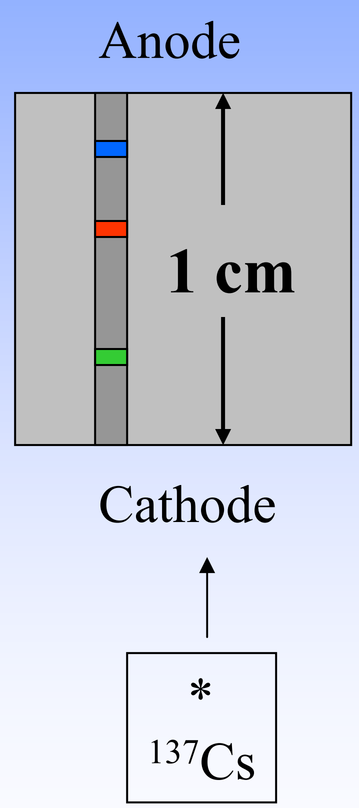
HgI_2 (#91321P91) = 12×12×10.05 mm

V(c) = - 2600 V; τ(c) = 10 μs; γ-rays incident from cathode

HgI_2 energy spectra versus interaction depth

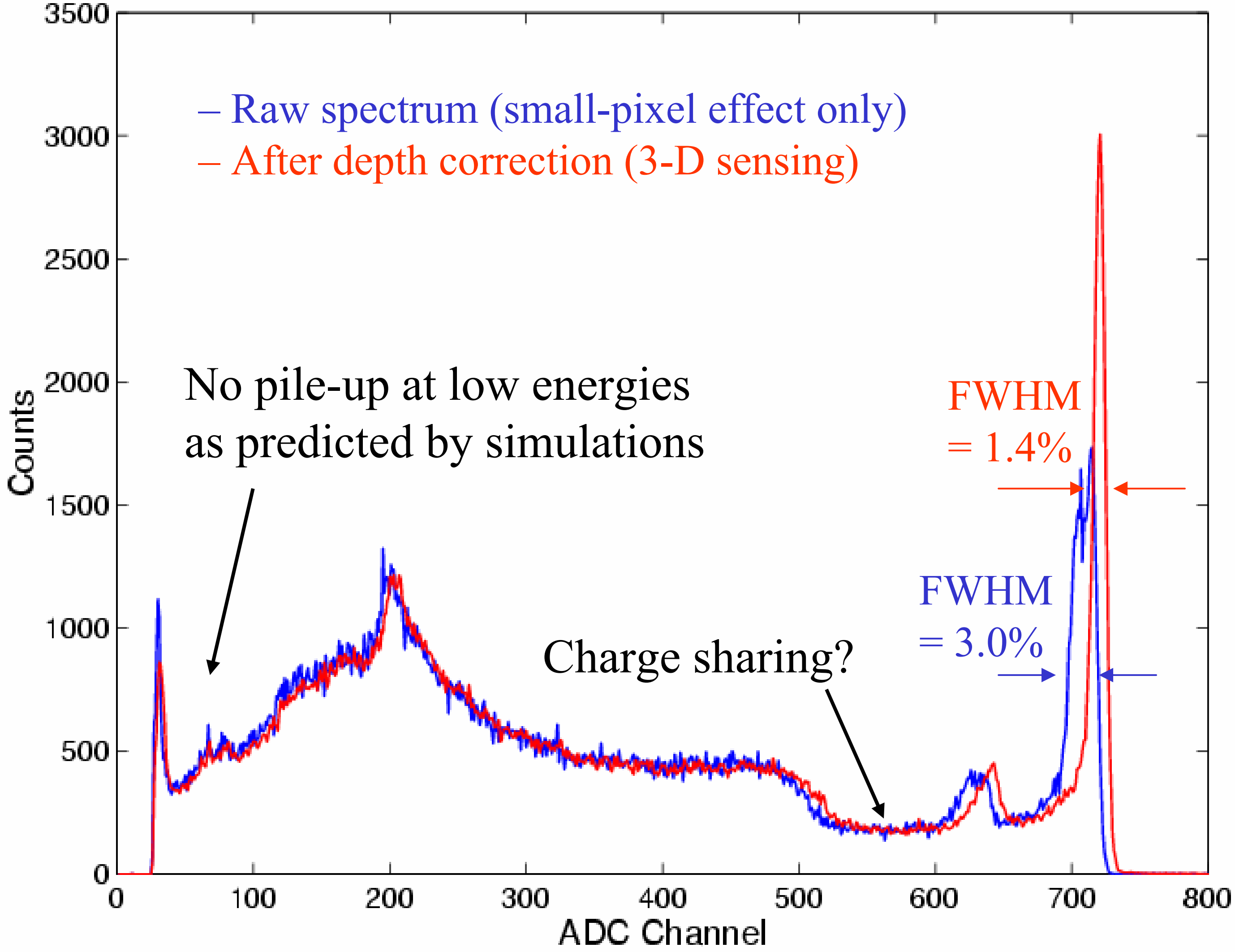
Detector: 93203N92; Pixel #2; V(c) = -2500 V; τ(a) = 16 μs; τ(c) = 8 μs

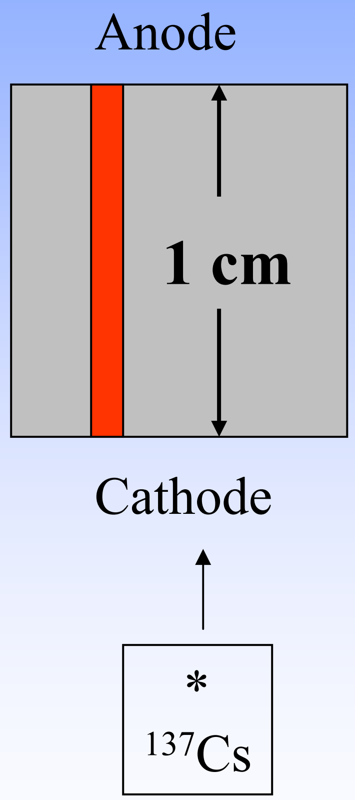




Energy spectrum from a 1cm thick HgI_2 detector

Detector: 93203N91; Pixel #2, V(c) = -2500 V; $\tau(a) = \tau(c) = 8\ \mu s$



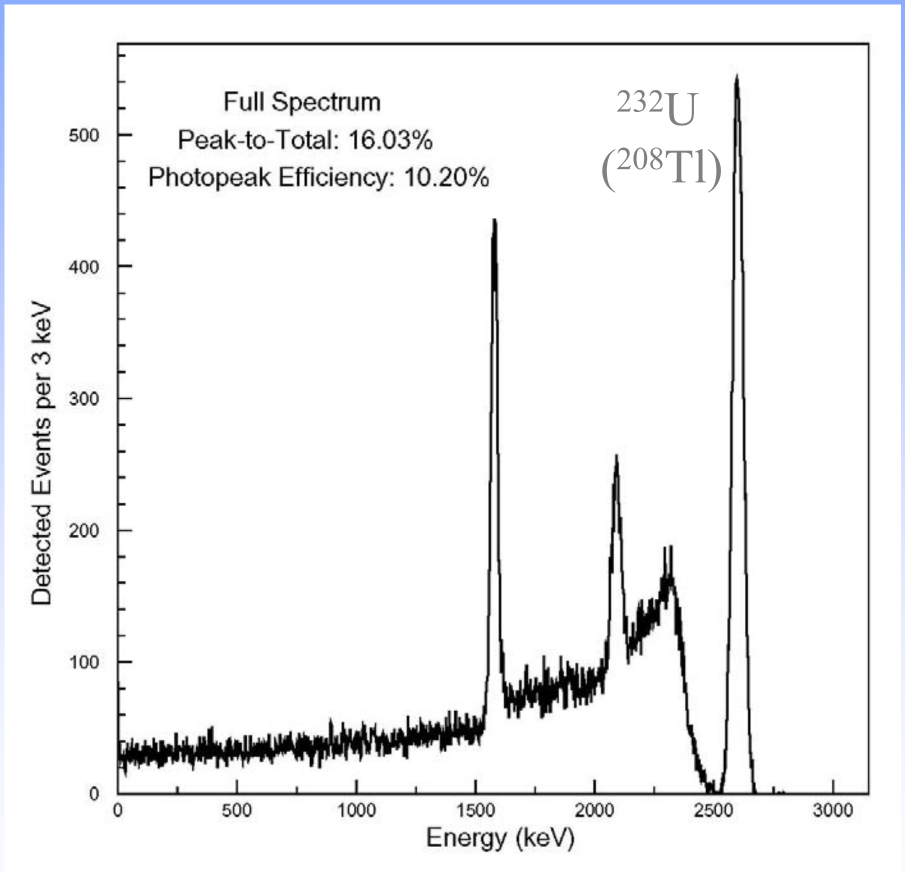


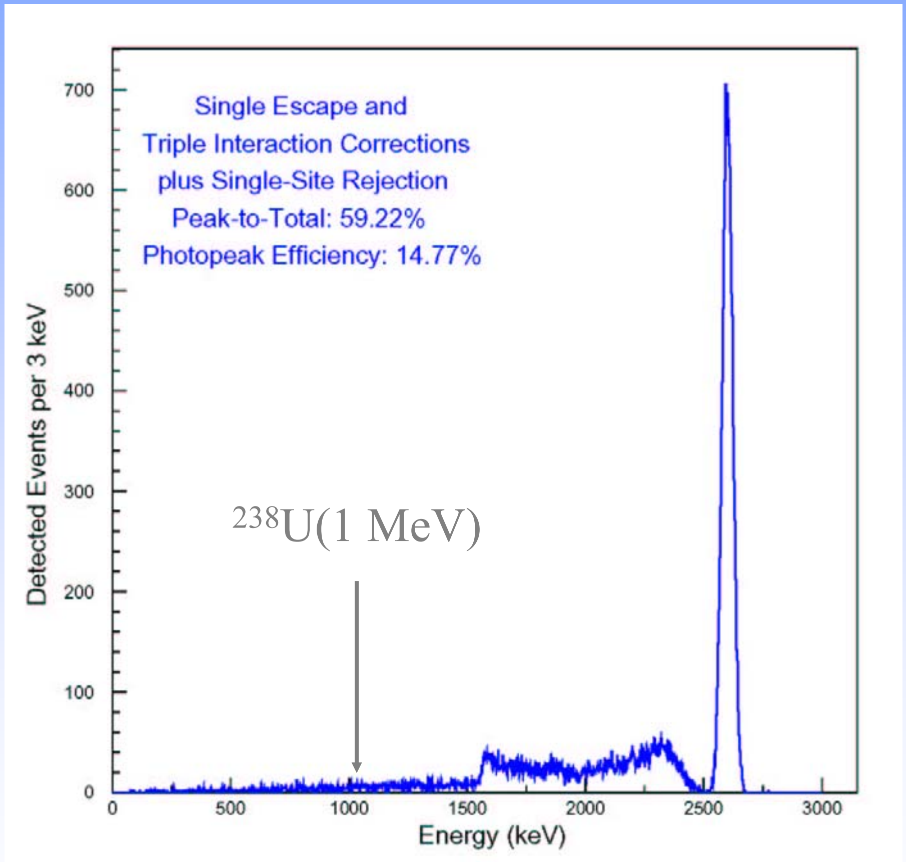
Conclusions on HgI_2

- It is possible to construct HgI_2 gamma-ray spectrometers at thickness ~ **1 cm** if a **3-D** position sensitive single-polarity charge sensing technique is employed, and using low biases (2-2.6 kV) and moderate shaping times (6-10 μs).
- Energy resolutions of 1.4% - 2% FWHM at 662 keV were obtained from 6 out of 7 pixel anodes.
- There is a potential to achieve better resolution on 1 cm thick devices.

Comparison between conventional and 3-D detectors for gamma spectroscopy

Detector = 2×2×4.5 cm CdZnTe





The sensitivity can be significantly improved
(Especially useful when the background is high)