"A Personal Perspective on the Evolution of Radiation Detectors"

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on Radiation Imaging Detectors

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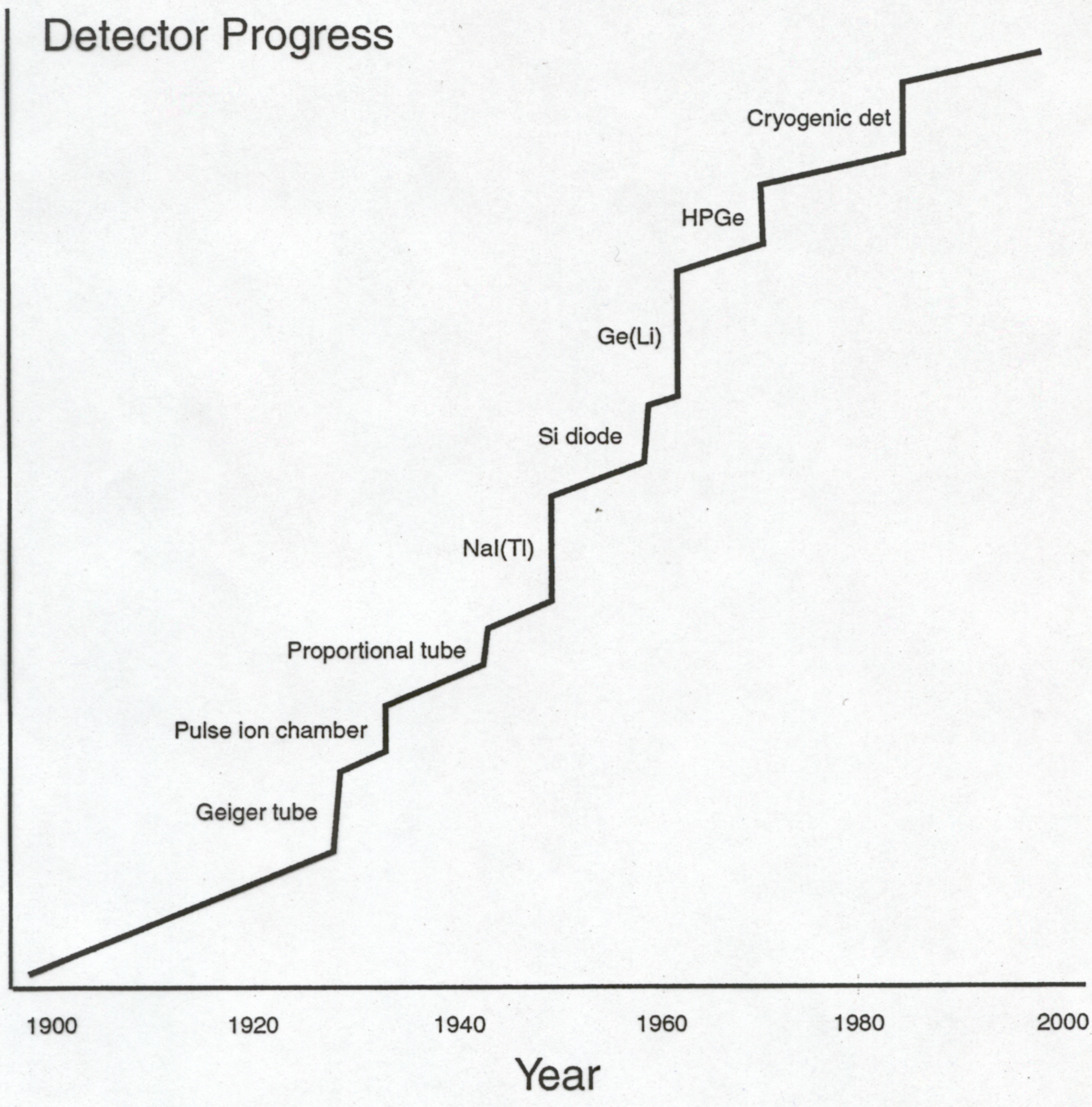
- Observations on the Development of Detectors
- Comments on the Evolution of Supporting Electronics
- Example of Use of New Electronic Capabilities:
  The 3-D Gamma Ray Spectrometer

Observations on the Development of Detectors

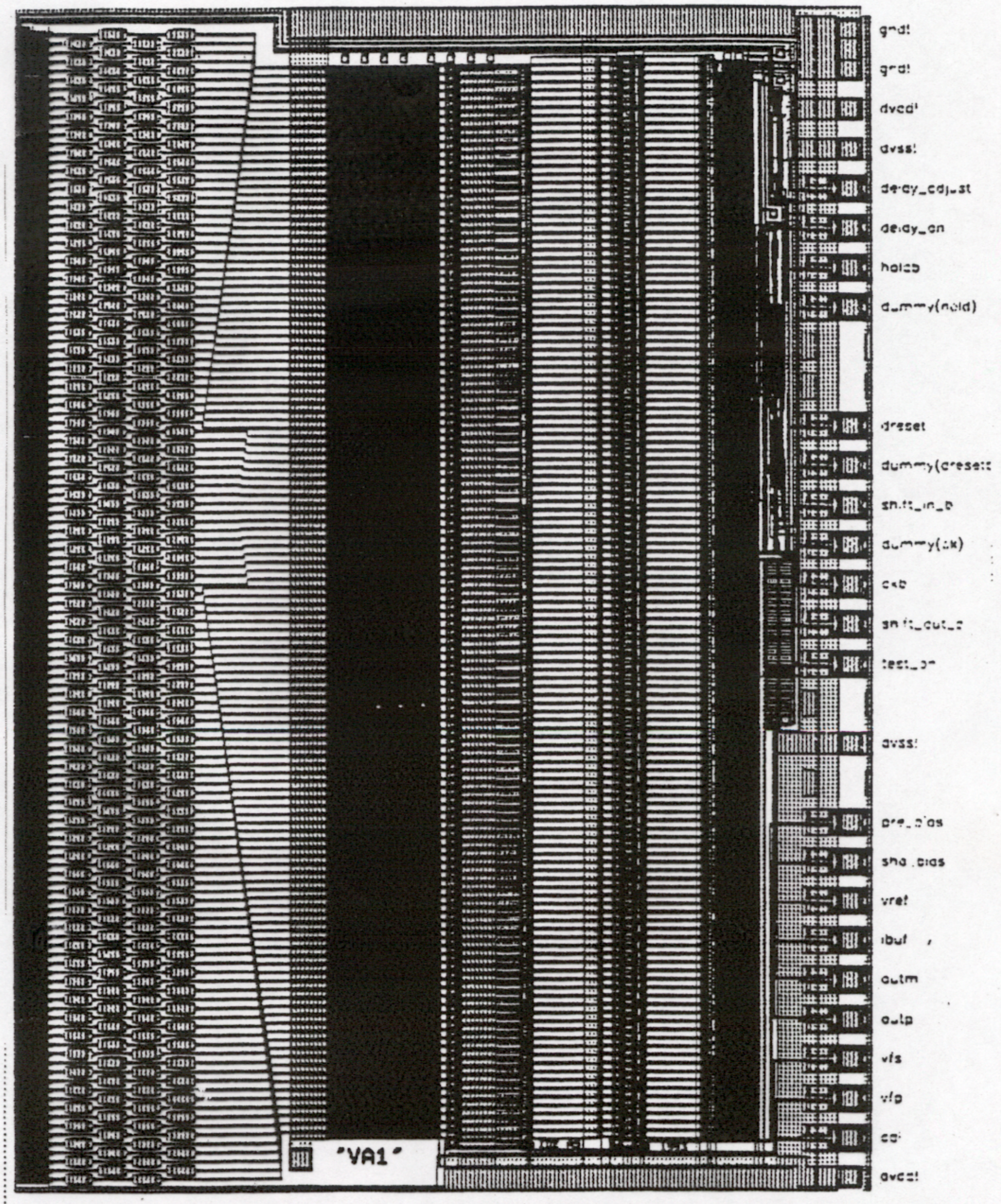
Note: Discussion limited to basic radiation detectors of importance in straightforward detection and spectroscopy of ionizing radiation. Will not be including imaging devices or tracking systems for particle physics.



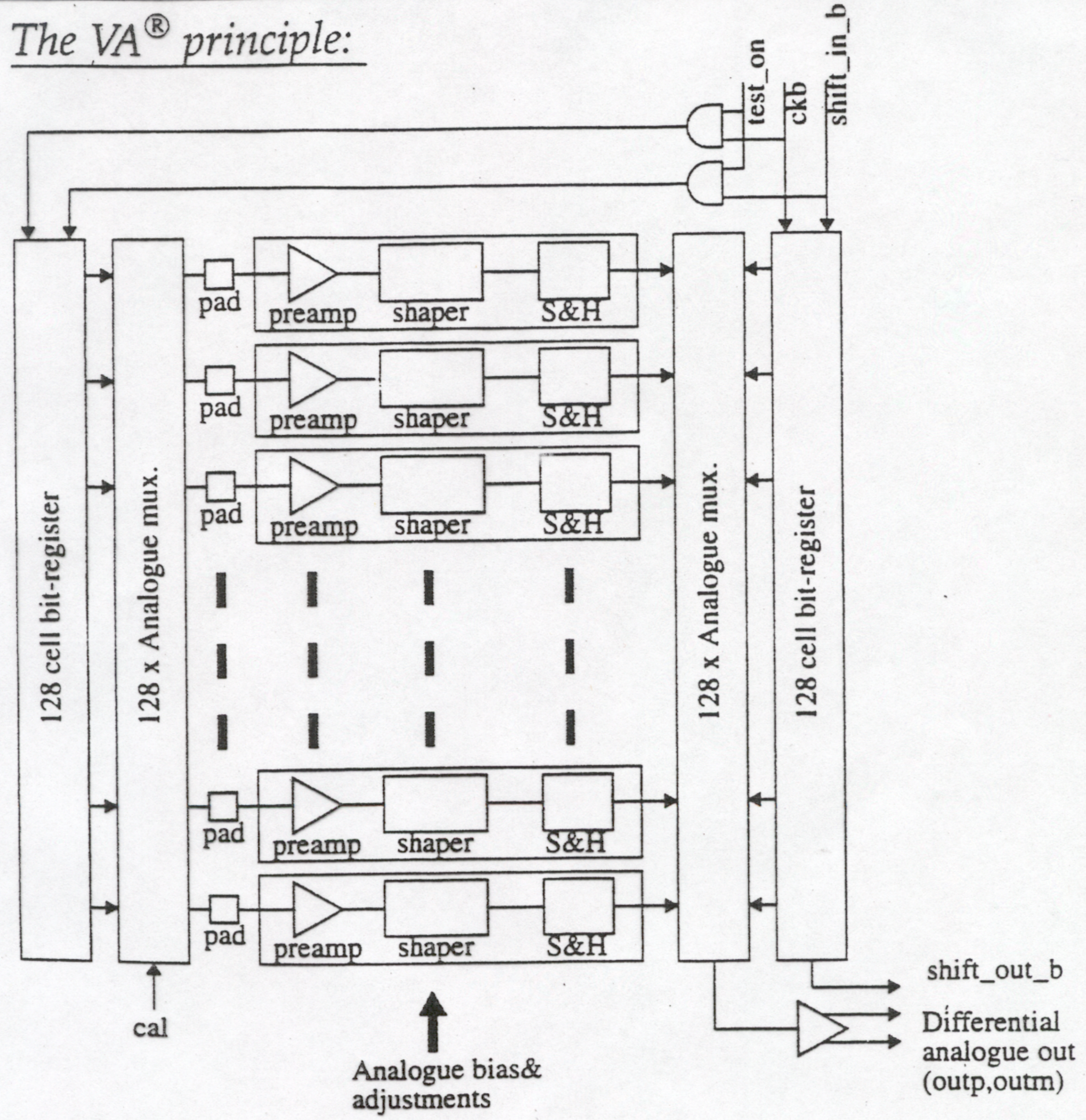
Detector Progress
Cryogenic det
HPGe
Ge(Li)
Si diode
NaI(Tl)
Proportional tube
Pulse ion chamber
Geiger tube
1900
1920
1940
1960
1980
2000
Year

Comments on the Evolution of Supporting Electronics

VA1 chip layout



The VA® principle:



		VA1	VA2	VA3
Equivalent Noise Charge	@ 1 µs	180 e- +7.5 e-/pF	80 e- +15.0 e-/pF	42 e- +18.6 e-/pF
	@ 2 µs	165 e- +6.1 e-/pF	60 e- +11.0 e-/pF	31 e- +15.0 e-/pF
Power Consumption		1.2 mW/channel	1.2 mW/channel	1.5 mW/channel
Peaking Time		0.5-3.0 µs	0.5-3.0 µs	0.5-3.0 µs
Dynamic Range		+/- 10 MIPs	+/- 4 MIPs	+/- 2 MIPs
Typical Applications		Big detectors with high capacitive load (60pF)	Medium sized detectors with cap. load around 10 pF	Short strip or pixel detectors.

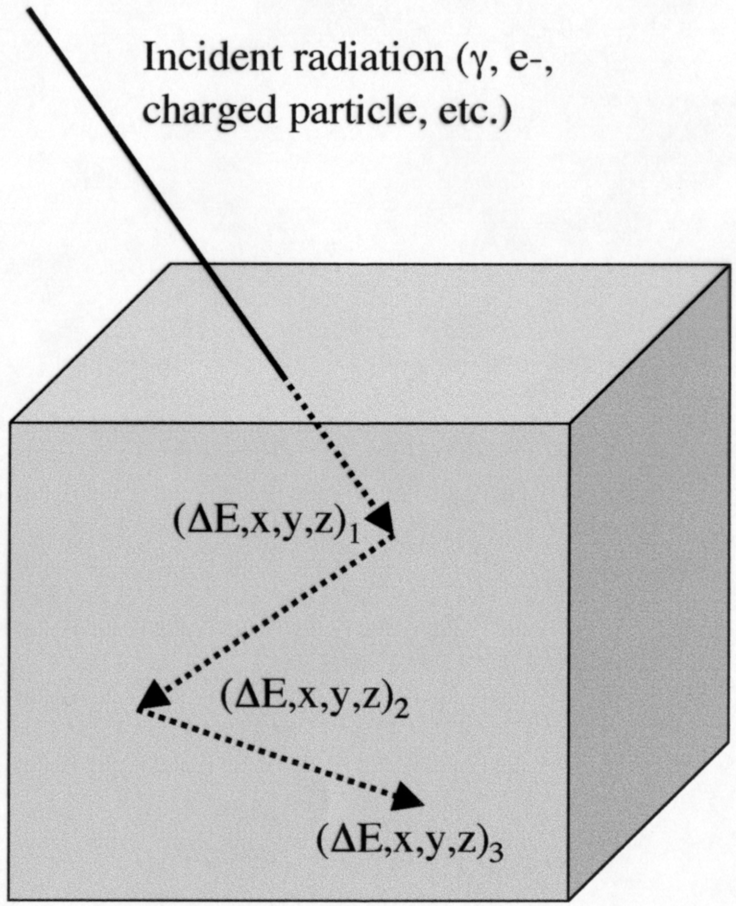
Example of the Use of New Electronic Capabilities: The 3-D Gamma Ray Spectrometer

Credit:

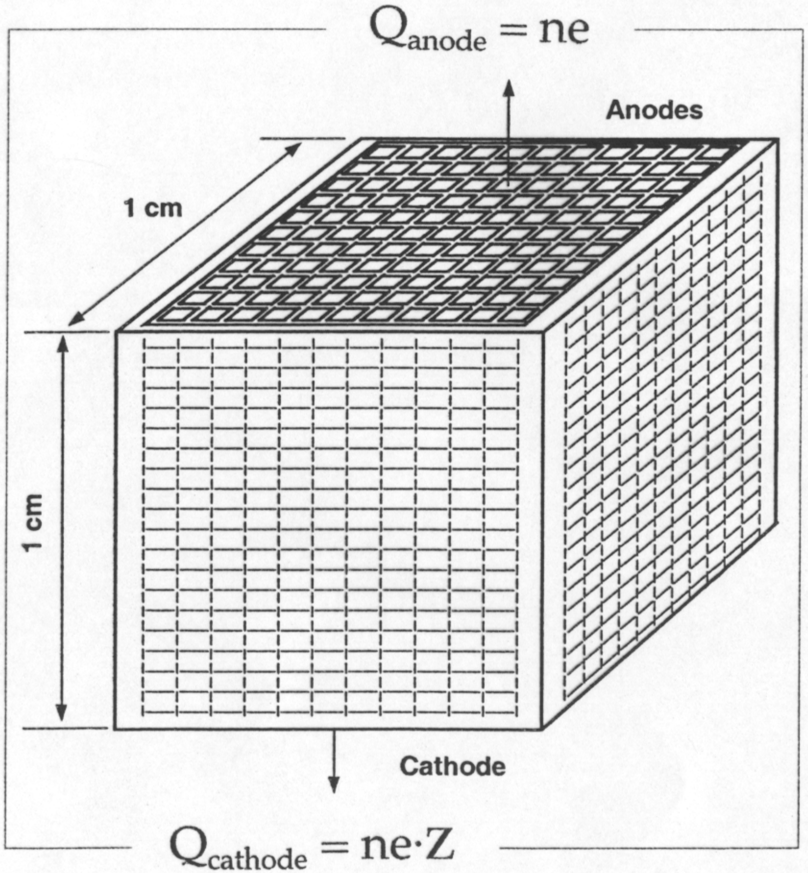
Profs. Zhong He and David Wehe
Cari Lehner, Feng Zhang, James Baciac, Dan Xu

University of Michigan

Volumetric semiconductor spectrometer with 3-D position sensitivity



3-Dimensional Position Sensitive CdZnTe Detector



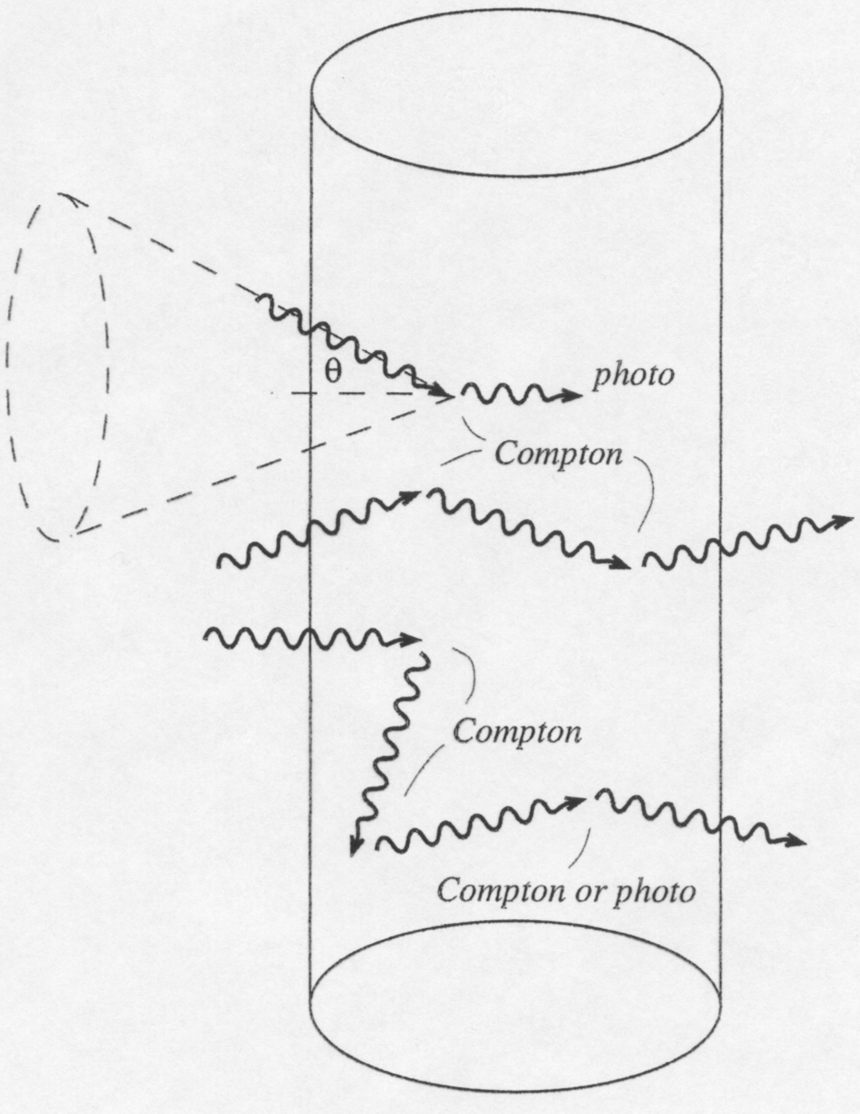
- Energy Resolution: 1.5% FWHM (single site) at 662 keV
- Position Resolution: 1(x)×1(y)×0.5(z) mm

Ref. Z.He et al, Nucl. Instr. Meth., A422(1998)173-178

Why do we need 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 (Enhancement on performance based on the signatures of radiation interactions)

Volumetric Compton Imaging

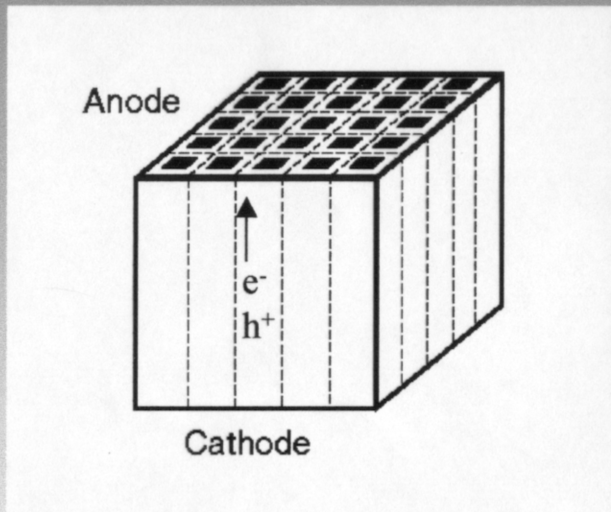


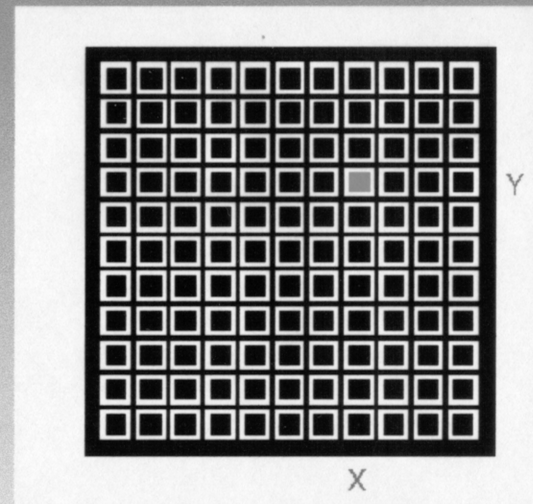
Requires 3-D position-resolved energy measurements

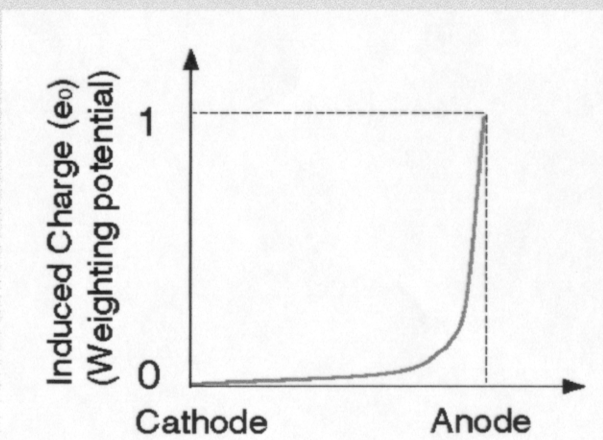
Challenges in Volumetric Compton Imaging

- Must measure 3-D position and energy deposition for each multiple interaction of incident photon
- Getting information on initial direction of first recoil electron would eliminate azimuthal ambiguity, but has not yet been successfully demonstrated
- Small voxels minimize information loss due to multiple interactions in a single voxel, but require fine granularity and complex readout
- Larger voxels can interpolate single event position via spectator signals, but now must deal with more complex analysis due to multiple interactions per voxel
- The exact sequence of multiple events is needed for Compton reconstruction, but direct timing not likely to give required time resolution. Must deduce sequence indirectly.

3-D position sensing in CZT



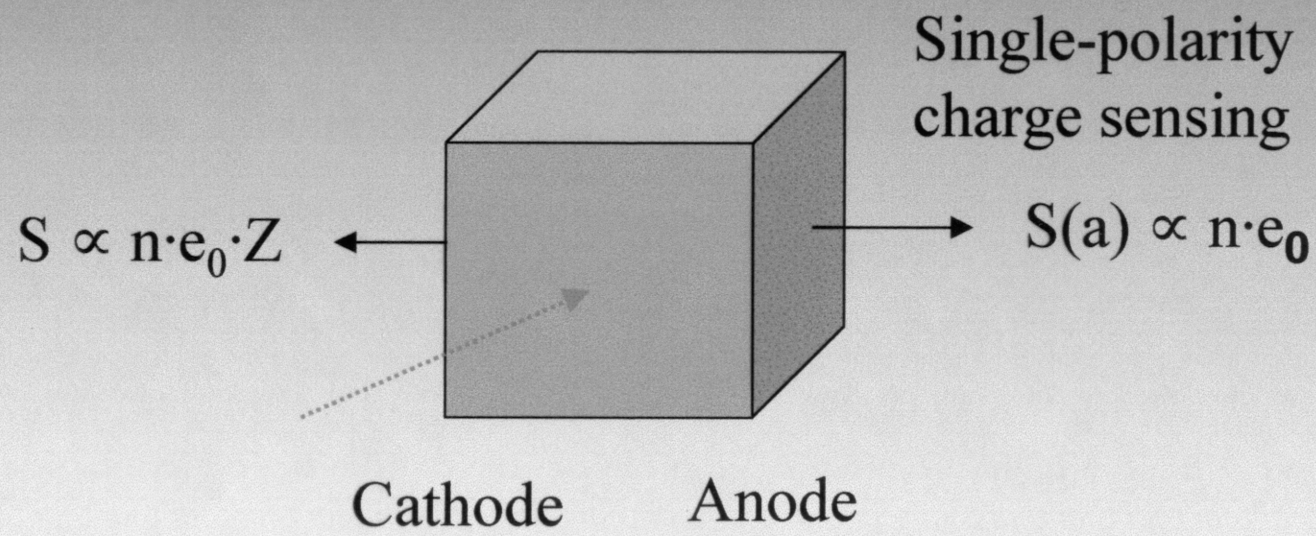




Get x and y from pixel location

Get z from C/A ratio

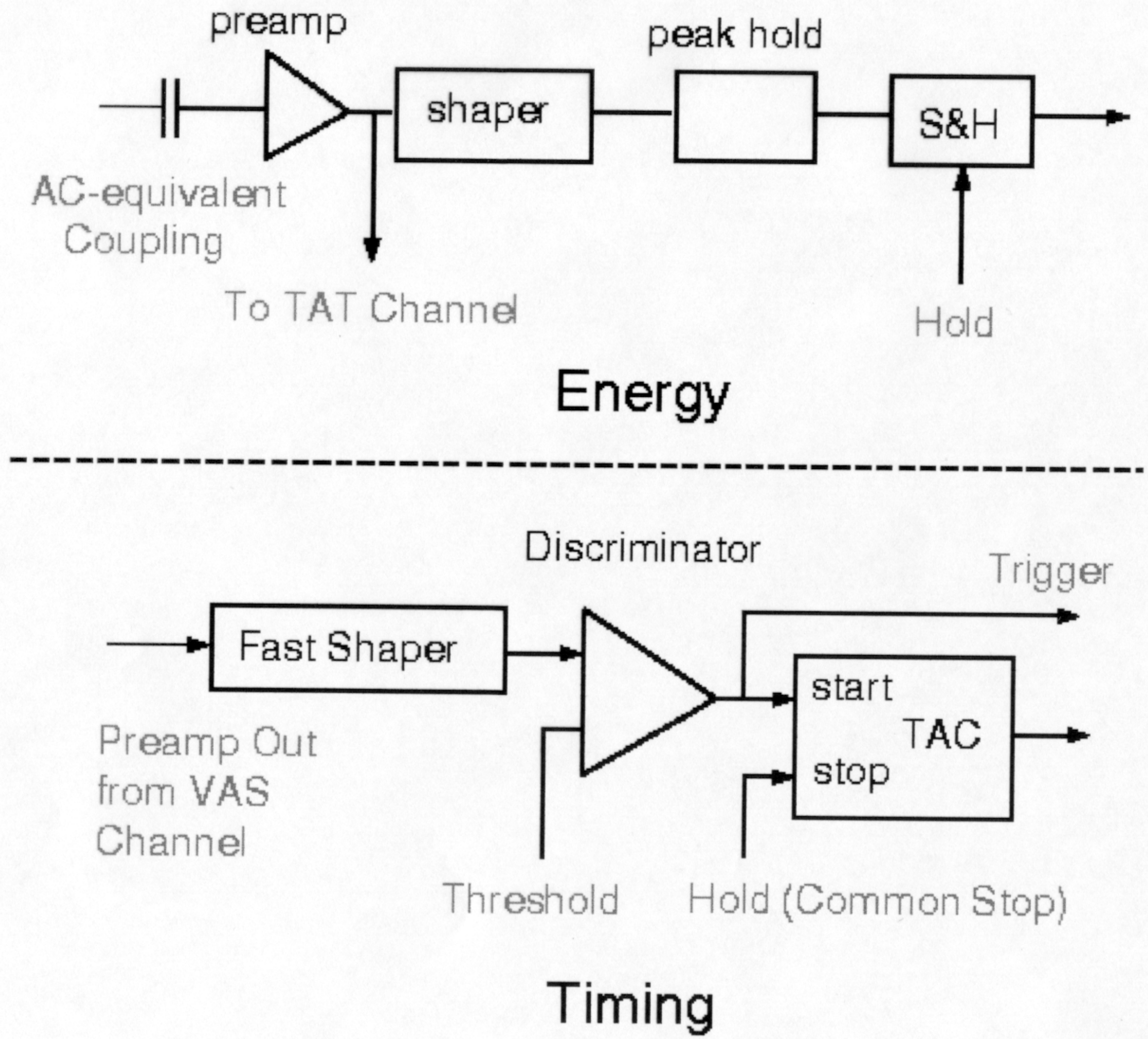
The ratio depth-sensing technique



$S(a) \Rightarrow$ Energy

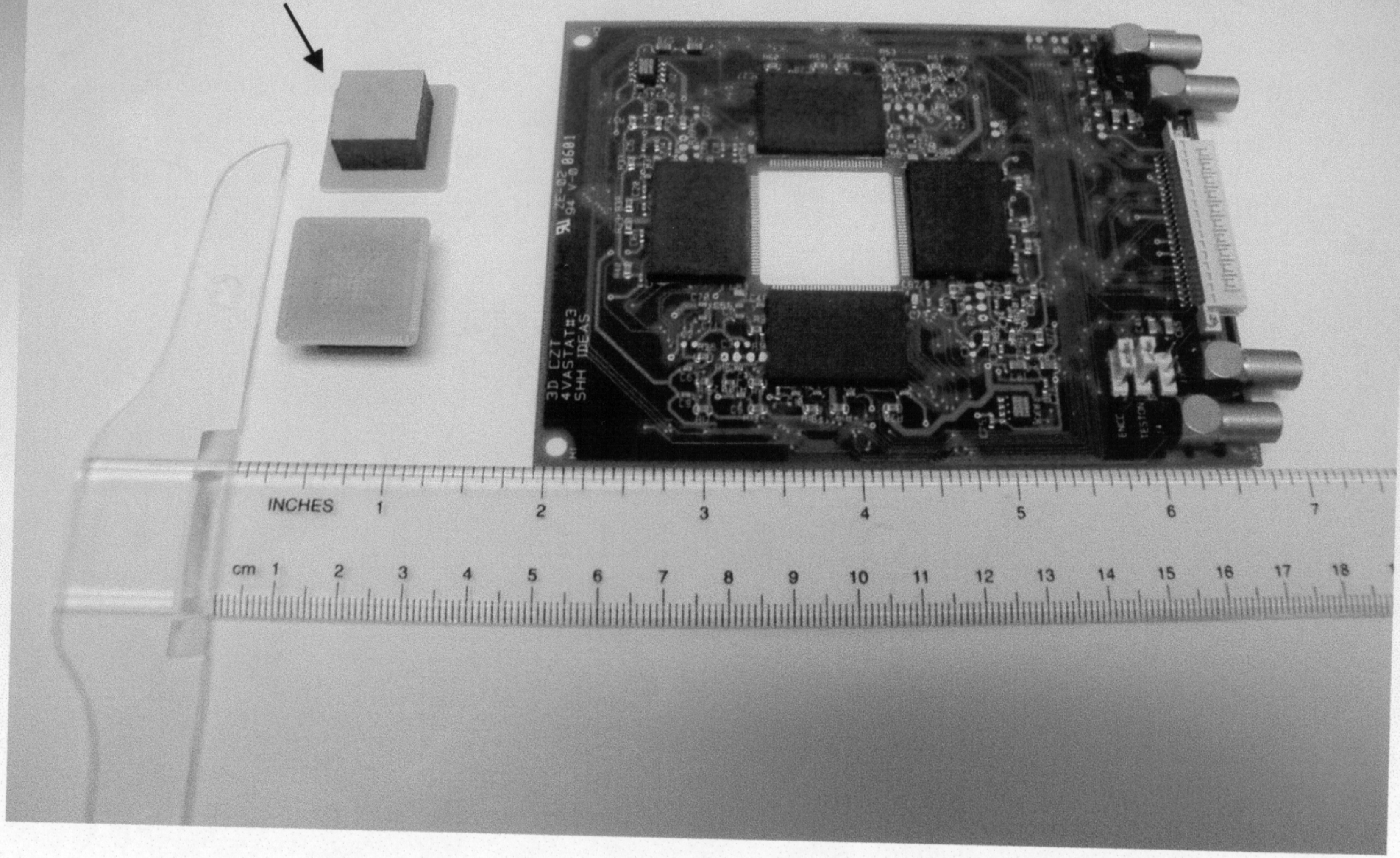
$S(c)/S(a) = ne_0Z/ne_0 \Rightarrow$ Depth of interaction

The key component (ASIC)



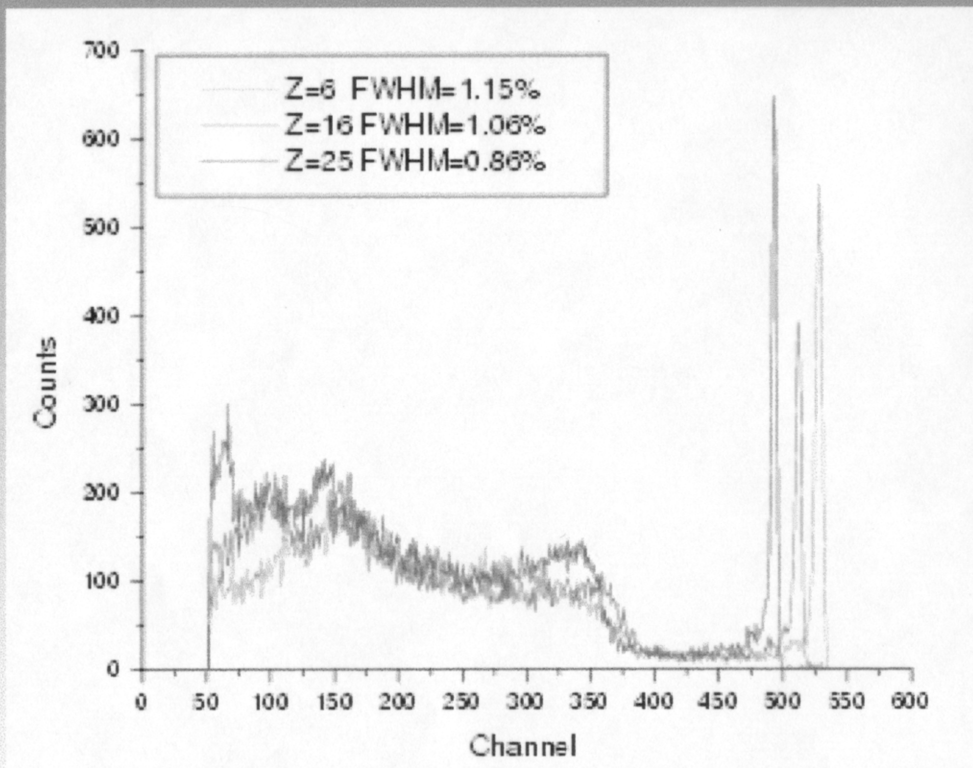
Top view of the 2^{nd} generation system

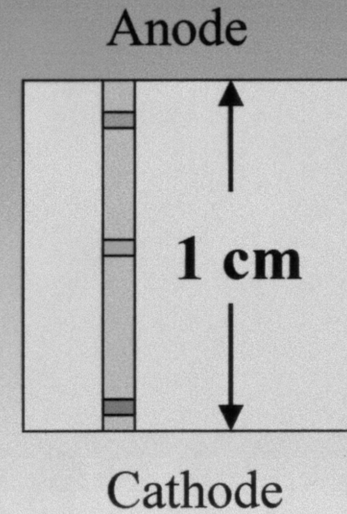
Detector dimensions: 1.5×1.5 ×1 cm

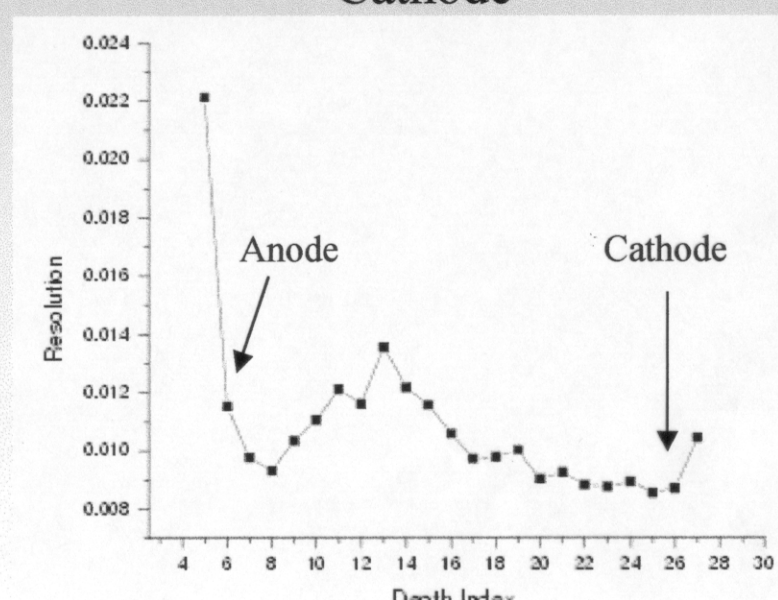


Energy spectra from voxels (pixel #91)

(Detector # 2.4, readout using discrete electronics)



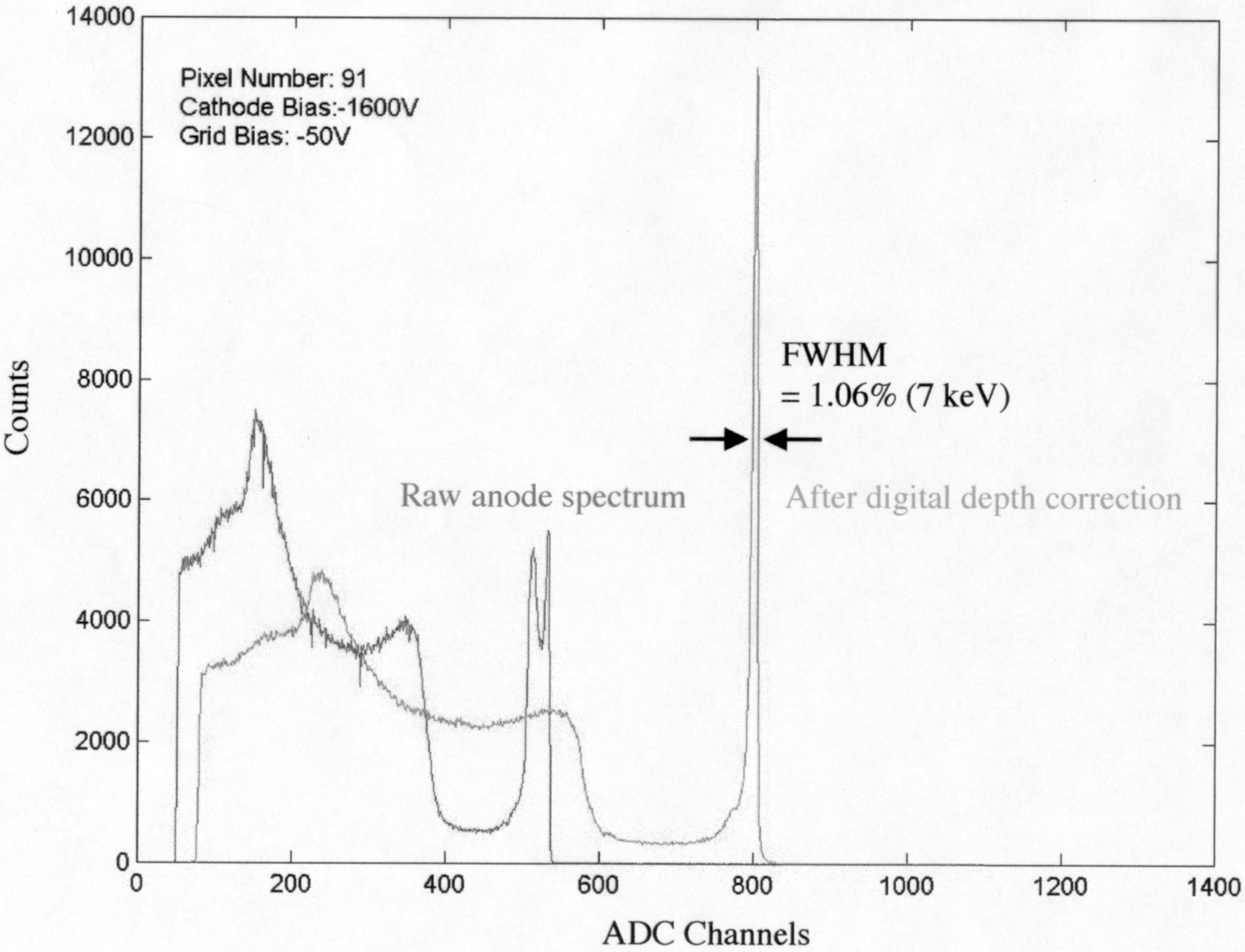


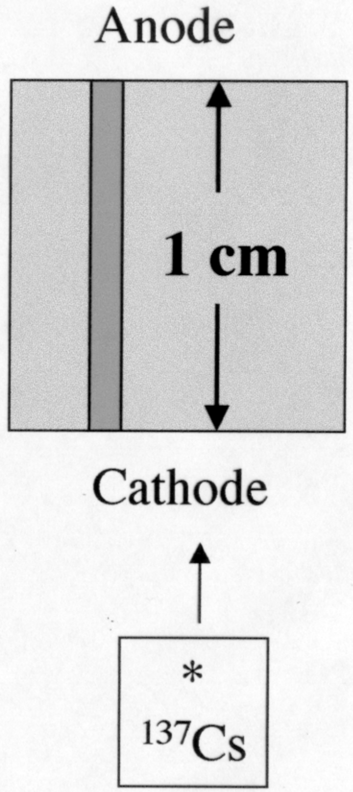


$\Delta E/E$ is best near the cathode!

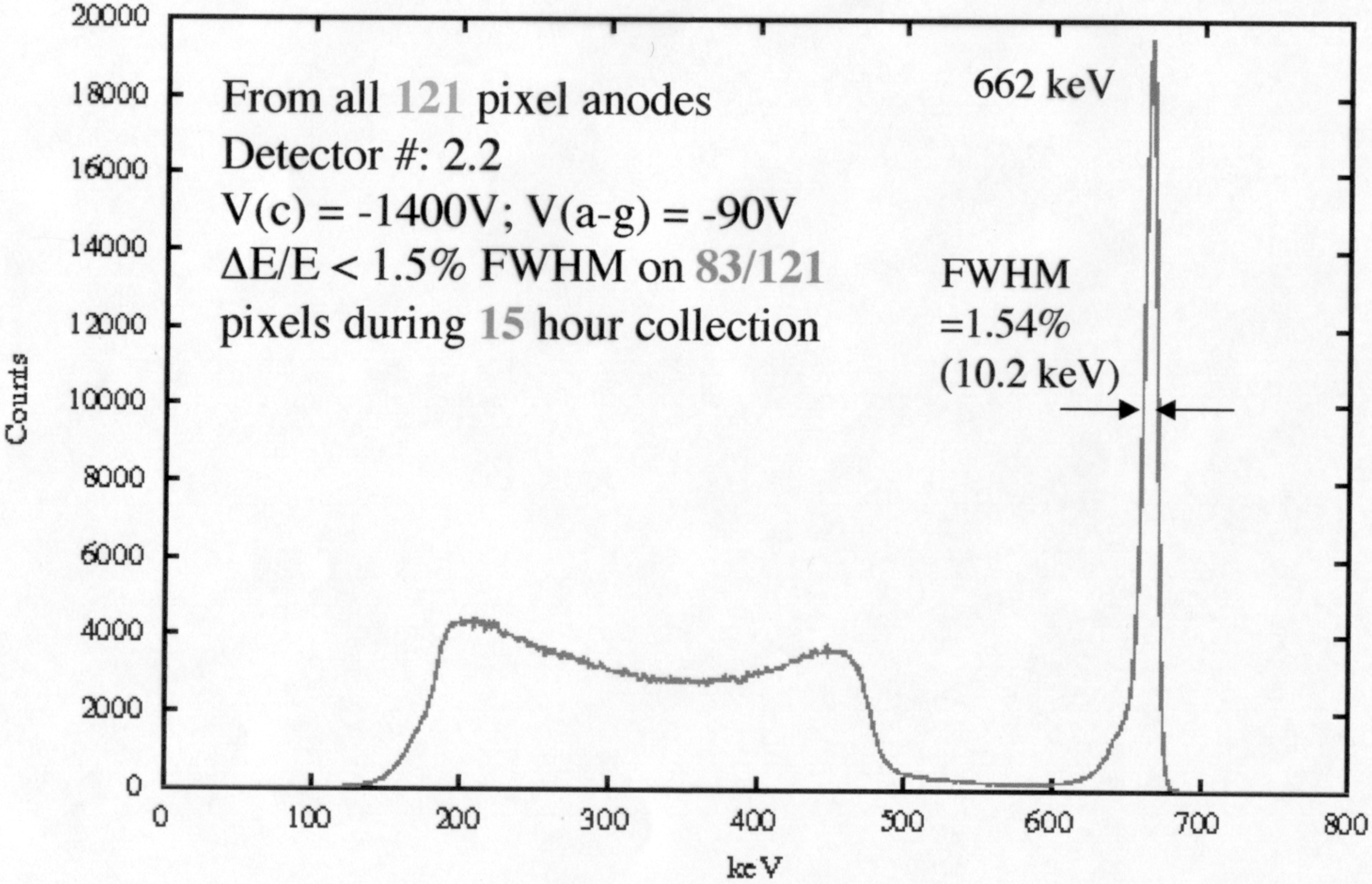
An energy spectrum from one pixel anode

(Detector # 2.4, readout using discrete electronics)



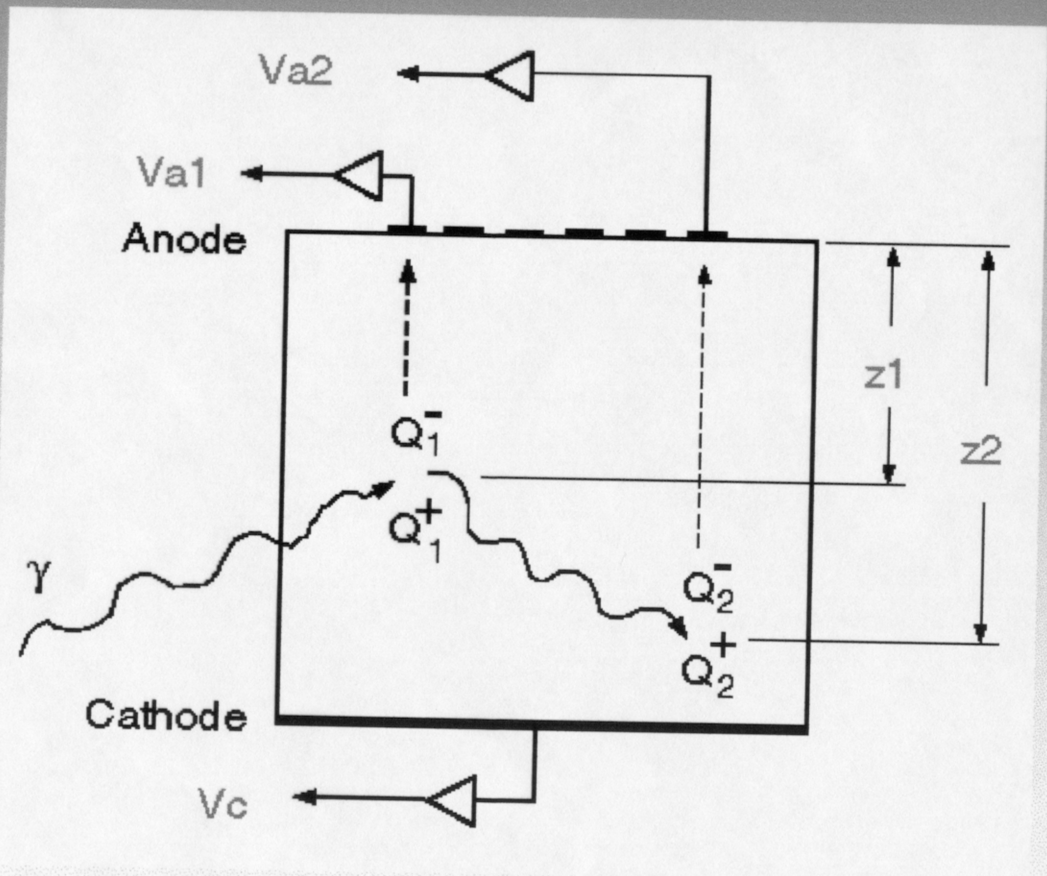


The energy spectrum of single-pixel events



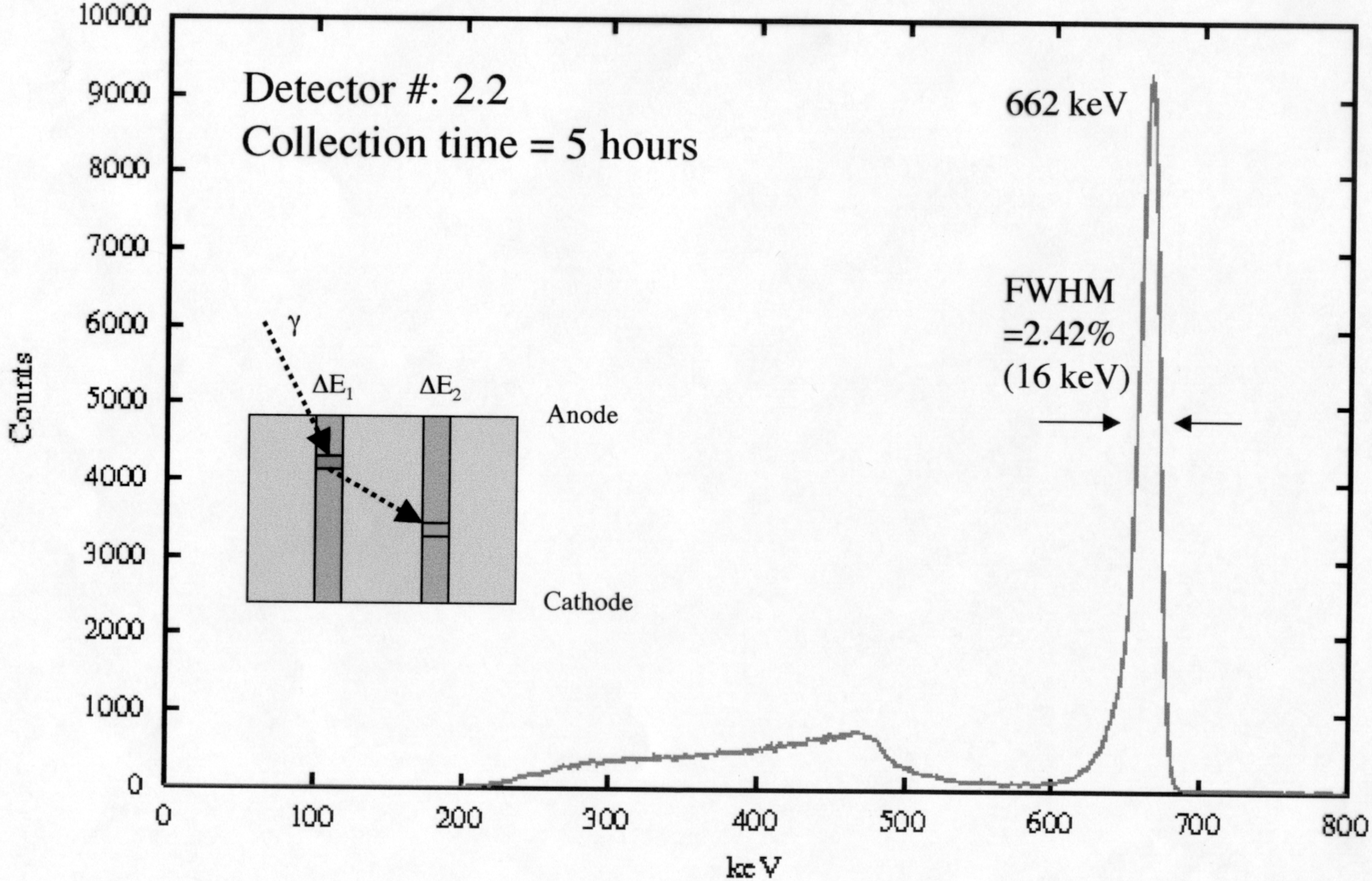
After corrections for electron trapping, material non-uniformity, variation of gain & baseline shift versus temperature, and non-linearity.

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

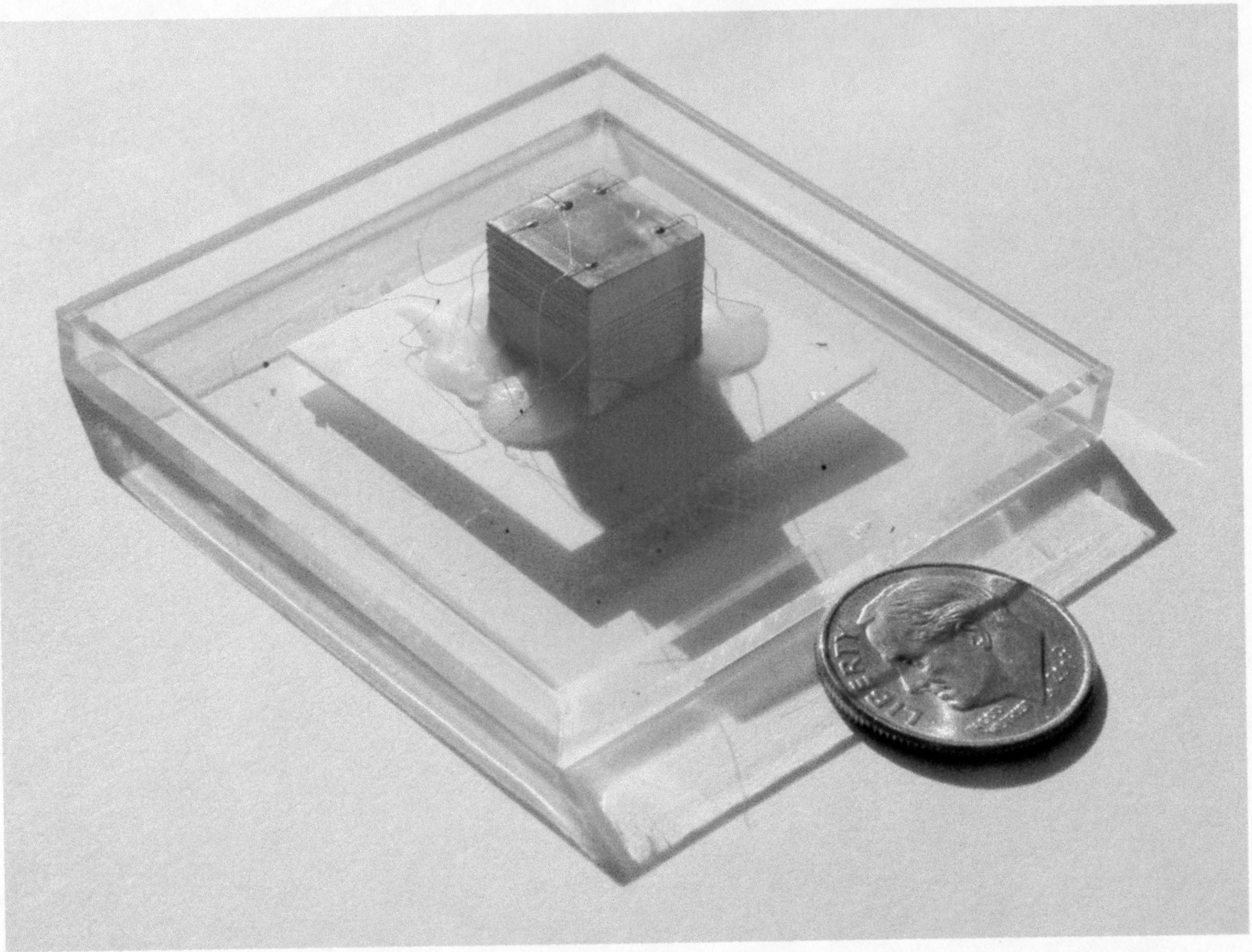


- Need $\Delta Z_i = Z_i - Z_{i+1}$ to obtain individual interaction depths

Energy spectra from two-pixel events

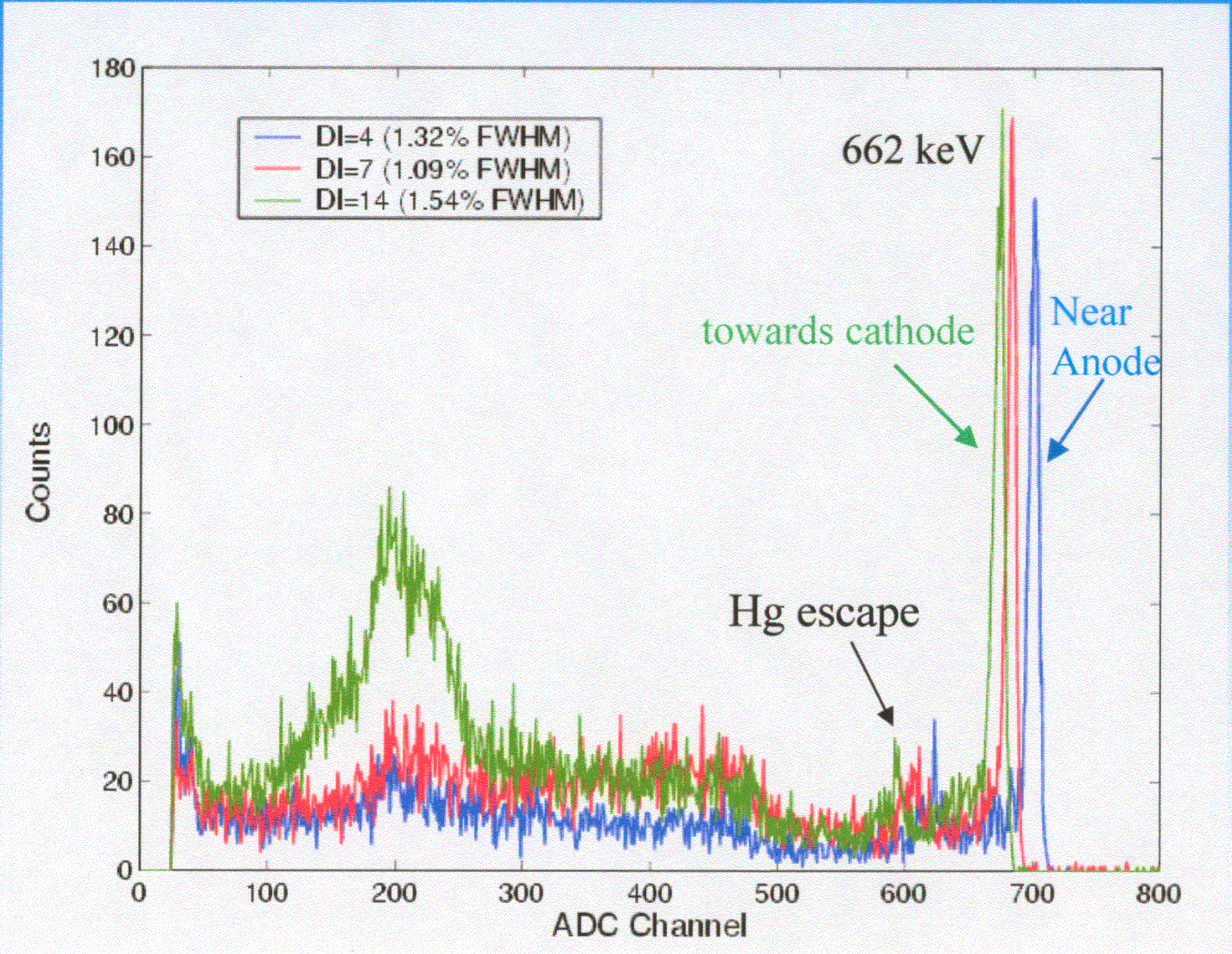


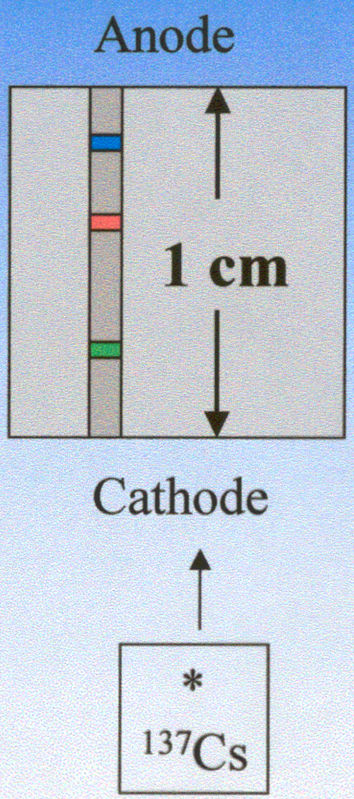
A sample 1cm thick HgI_2 detector



HgI_2 energy spectra versus interaction depth

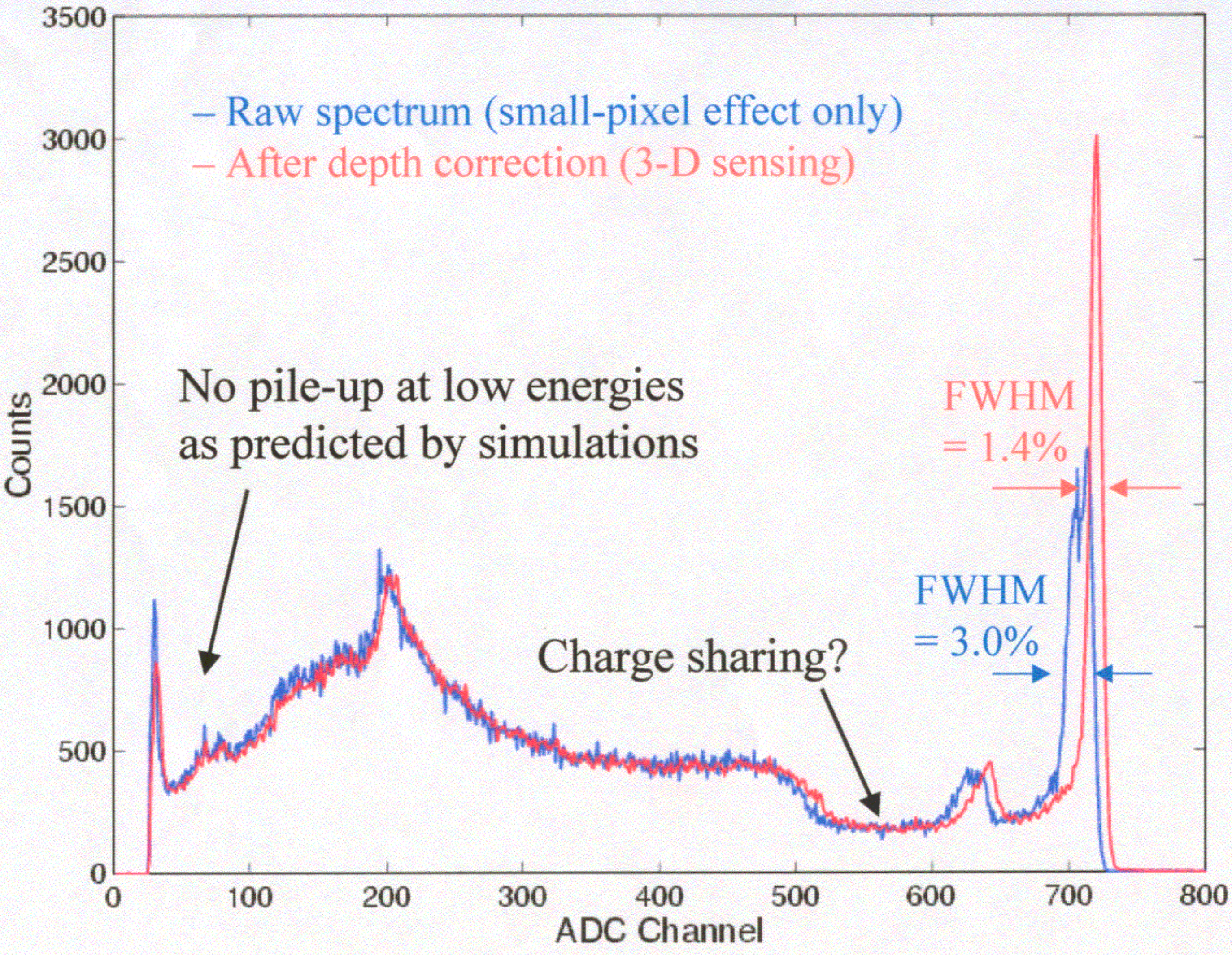
Detector: 93203N92; Pixel #2; V(c) = -2500 V; τ(a) = 16 μs; τ(c) = 8 μs

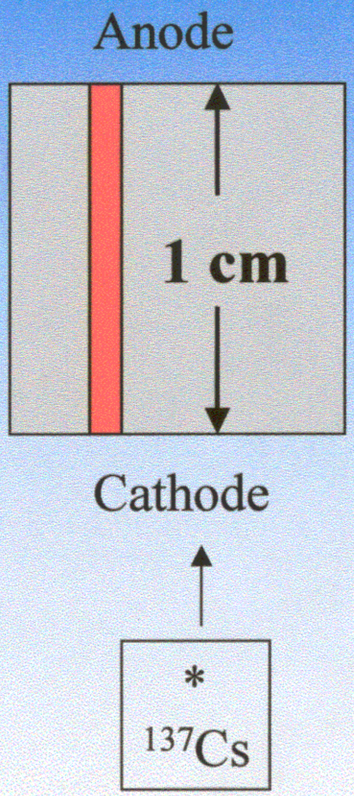




Energy spectrum from a 1cm thick HgI_2 detector

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





"Intelligent" Gamma Ray Spectroscopy

In a conventional germanium crystal or scintillation detector, pulses that are recorded may be the result of single or multiple interactions of the incident gamma ray photon. In standard gamma ray spectroscopy, there is no way to differentiate between pulses based on the number or type of gamma ray interactions that have taken place.

In a 3-D gamma ray spectrometer, additional information is available:

- The number of interactions of each gamma ray is determined
- The energy deposited in each of these interactions is separately recorded
- The 3-D coordinates of each interaction are also measured

This additional information can be used to significantly improve the quality of the pulse height spectrum produced by the detector.

Take advantage of 3-D position-sensing capability for gamma spectroscopy

Detector = 2×2×4.5 cm CdZnTe